TISA Working Group Update

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CERES Science Team Meeting

Virtual Covid-19 Meeting, September 15-17, 2020

OUTLINE

- The transition from Aqua to NOAA-20 in the SSF1deg and SYN1deg products
  - Aqua stopped transmitting data between Aug 16 and Sept 2, 2020
- Migrating towards NOAA-20 VIIRS as the forward processing imager to inter-calibrate GEOs while maintaining the Aqua-MODIS calibration reference
- GOES-17 temporal interpolation of clouds and fluxes across 6-hours of nighttime unusable IR channel saturated imagery
- GEO shortwave narrowband to broadband progress for Edition 5

GEO/imager Calibration and TISA Publications

- R. Bhatt, D.R. Doelling, A. Angal, X. Xiong, C.O.Haney, B.R. Scarino, A. Wu, A. Gopalan, "Response Versus Scan-Angle Assessment of MODIS Reflective Solar Bands in Collection 6.1 Calibration," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 58, no. 4, pp. 2276-2289, April 2020, doi: 10.1109/TGRS.2019.2946963.
- Rajendra Bhatt, David R. Doelling, Conor O. Haney, Douglas A. Spangenberg, Benjamin R. Scarino, Arun Gopalan, "Clouds and the Earth's Radiant Energy System strategy for intercalibrating the new-generation geostationary visible imagers," J. Appl. Rem. Sens. 14(3) 032410 (7 August 2020)https://doi.org/10.1117/1.JRS.14.032410
- Hewison, T.J.; Doelling, D.R.; Lukashin, C.; Tobin, D.; O. John, V.; Joro, S.; Bojkov, B. Extending the Global Space-based Inter-Calibration System (GSICS) to Tie Satellite Radiances to an Absolute Scale. Remote Sens. 2020, 12, 1782.
- Helder, D.; Doelling, D.; Bhatt, R.; Choi, T.; Barsi, J. Calibrating Geosynchronous and Polar Orbiting Satellites: Sharing Best Practices. *Remote Sens.* **2020**, *12*, 2786.
- Scarino, B., Bedka, K., Bhatt, R., Khlopenkov, K., Doelling, D. R., and Smith Jr., W. L.: A kernel-driven BRDF model to inform satellite-derived visible anvil cloud detection, *Atmos. Meas. Tech*., https://doi.org/10.5194/amt-2020-206, **Accepted**, 2020.
- Scarino, B., Doelling, D. R., Bhatt, R., Gopalan, A., Haney, C.: Evaluating the magnitude of VIIRS out-of-band response for varying earth spectra, Remote Sens., In review, 2020.
- Loeb, N.G.; Doelling, D.R., CERES Energy Balanced and Filled (EBAF) from Afternoon-Only Satellite Orbits. *Remote Sens.* **2020**, *12*, 1280.
- Scott, R. C., T. A. Myers, J. R. Norris, M. D. Zelinka, S. A. Klein, M. Sun, and D. R. Doelling, 2020: Observed Sensitivity of Low-Cloud Radiative Effects to Meteorological Perturbations over the Global Oceans. *J. Climate*, **33**, 7717–7734, https://doi.org/10.1175/JCLI-D-19-1028.1
- M. Sun, D.R. Doelling, J. Wilkins, L.T. Nguyen, P. Mlynczak, R.C. Scott, Clouds and the Earth's Radiant Energy System (CERES) FluxByCldTyp Edition 4 Data Product, JTECH, in preparation, submit at end of month

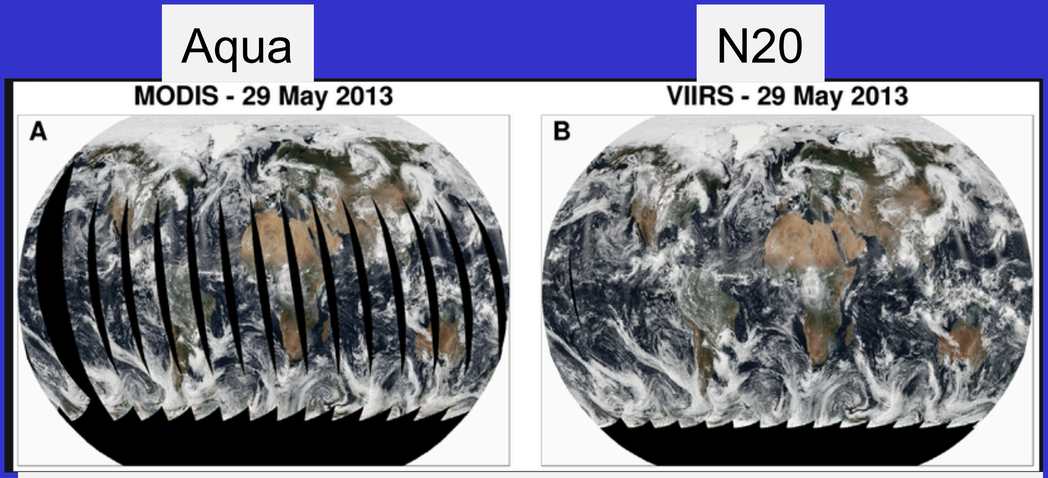
Migrating SYN1deg from Aqua to NOAA20

Migrating SYN1deg from Aqua to NOAA20

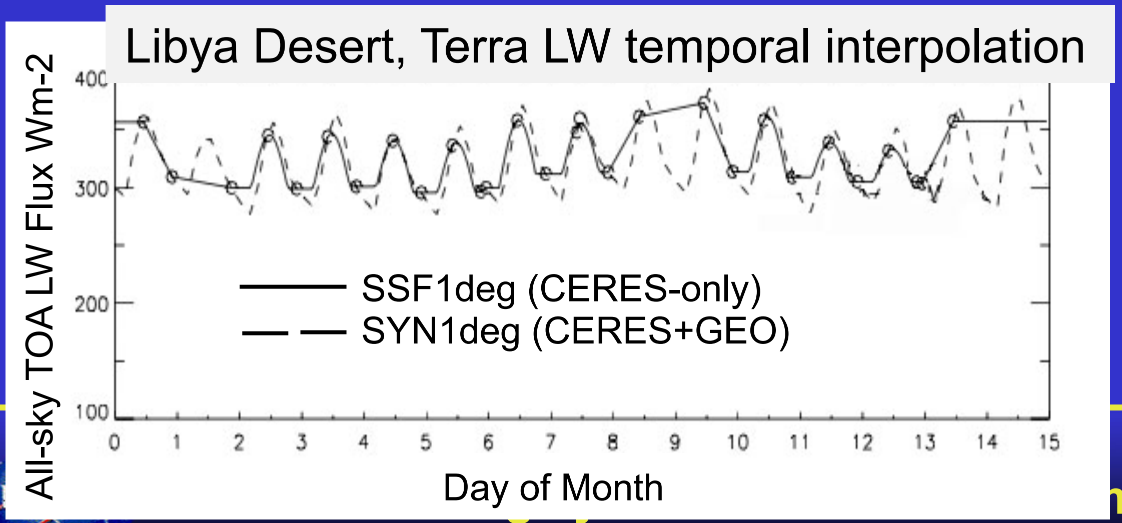
- Aqua stopped transmitting data between Aug 16 and Sept 2, 2020
  - There was no way of knowing if the problem could be corrected
- The TISA group was tasked with migrating Aqua based TISA products to NOAA20 based products
  - The NOAA-20 CERES FM 6 sensor is the best understood CERES instrument
  - NPP has been in RAPS mode for the last year. Cross-track scanning required for spatially complete TISA datasets.
  - The NOAA-20 CERES instrument was radiometrically scaled to the Terra FM1 calibration reference, as were all other CERES sensors
- Determine if appending the Terra+N20 SYN1deg with the Terra+Aqua SYN1deg will be seamless
- TISA has scripted the EBAF, SSF1deg-lite and SYN1deg-lite forward processing. Able to run 2 years of EBAF data in a few days

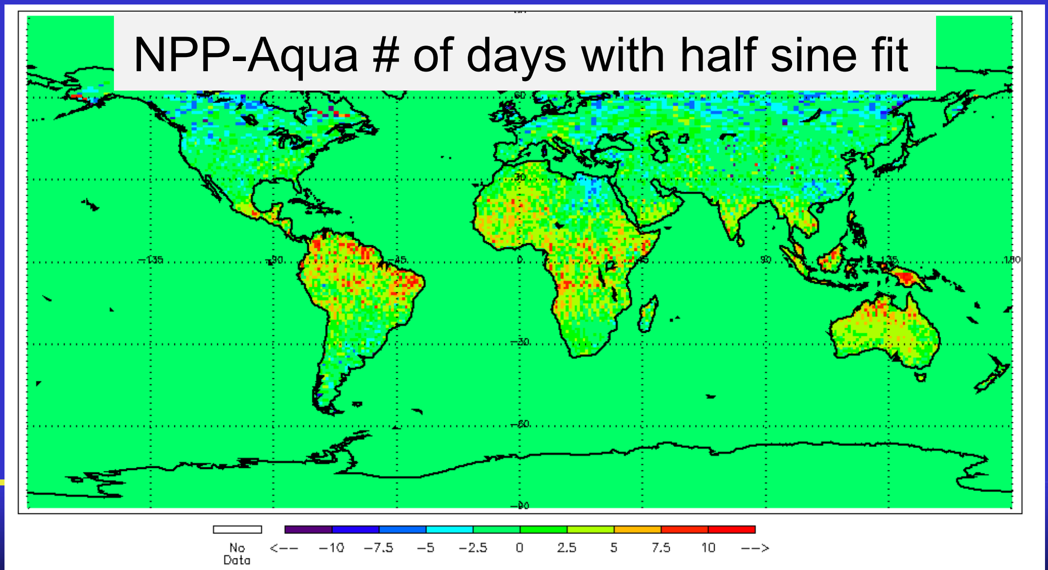
N20 vs Aqua

- N20 has an altitude of 830 km, whereas Aqua is 720 km.
- This prevents Aqua cross-track swaths from overlapping at the equator
- For the half sine fit to estimate the desert hourly LW flux, there needs to be a daytime flux surrounded by nighttime LW fluxes



One day of cross track scanning

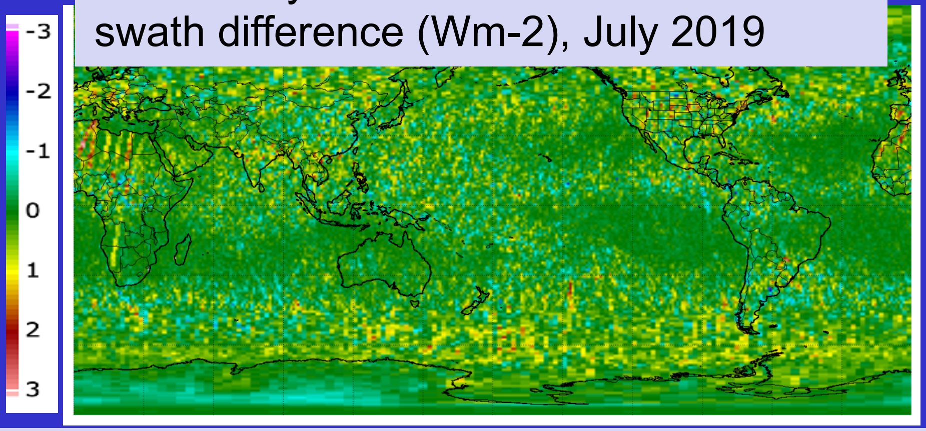




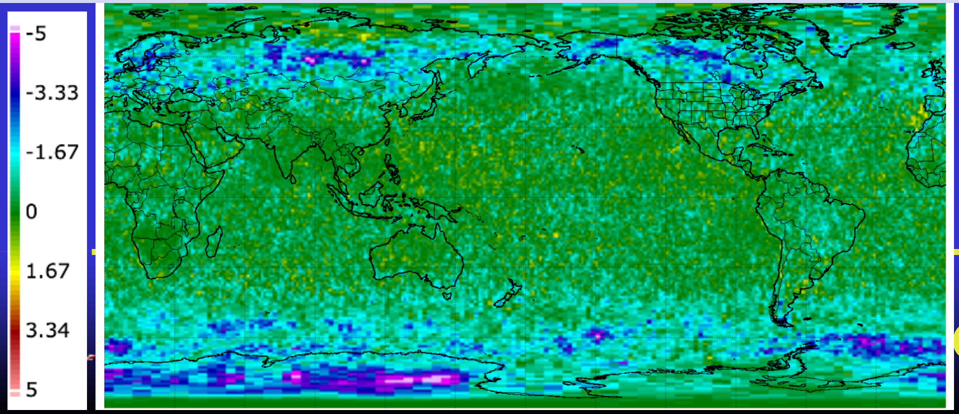
All-sky flux and cloud differences from limiting the N20 VZA<66°

- Terra and Aqua swath have a swath extent of 66° VZA, whereas NPP and N20 have a have a swath extent of 71° VZA, need to limit the N20 VZA<66°

N20 All-sky LW flux VZA<66° minus full swath difference (Wm-2), July 2019



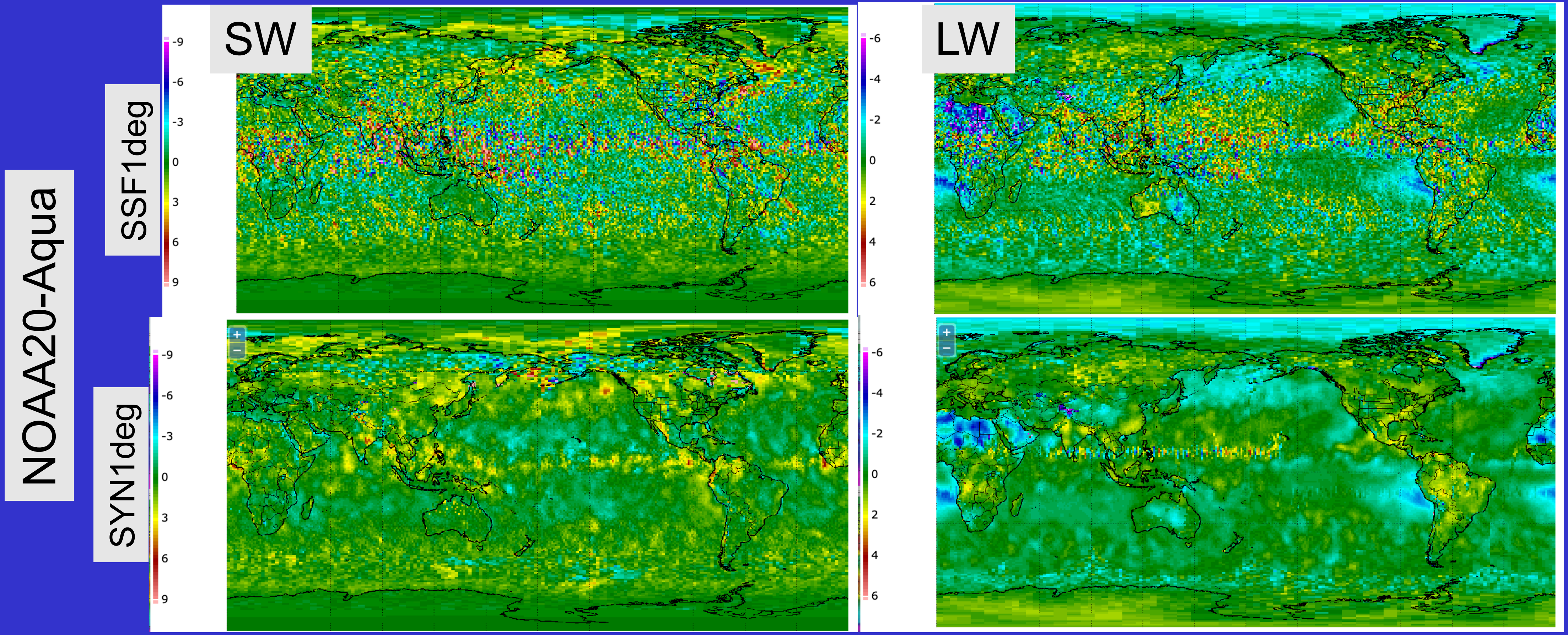
N20 All-sky 24-hour cloud fraction VZA<66° minus full swath difference (%), July 2019



VZA<66 minus full swath, global means, July 2019	NPP	N20
SW all-sky flux (Wm-2)	-0.035	0.015
SW clear-sky (Wm-2)	-0.043	-0.016
LW all-sky (Wm-2)	0.108	0.122
LW clear-sky (Wm-2)	0.046	0.062
24-hour cloud fraction%	-0.60	-0.54
24-hour cloud phase	0.0023	0.0021
Daytime cloud fraction%	-0.62	-0.50
Daytime cloud phase	0.08	0.06

- Apply a NPP and N20 VZA<66° threshold for SSF1deg and SYN1deg products

NOAA20 – Aqua SSF1deg and SYN1deg biases, August 2019



- The SSF1deg uses constant meteorology to compute 24-hour fluxes
- The SYN1deg product explicitly determines the hourly fluxes between CERES measurements using GEO derived broadband fluxes, which have been regionally normalized with CERES
- The N20 – Aqua SSF1deg and SYN1deg regional SW and LW all-sky biases are similar, indicating that the biases are not due to TISA temporal interpolation methods.
- Does not look like the # of LW half sine fit days impacted the monthly mean LW flux

NOAA20 – Aqua SSF1deg and SYN1deg during August 2019

SSF1deg

N20-Aqua	Global bias	Std of regional biases	N20 Global mean	Regional sigma
SW all	0.2948	2.2948	89.8	38.2 (6.0%)
LW all	-0.2243	1.3259	240.2	35.7 (3.7%)

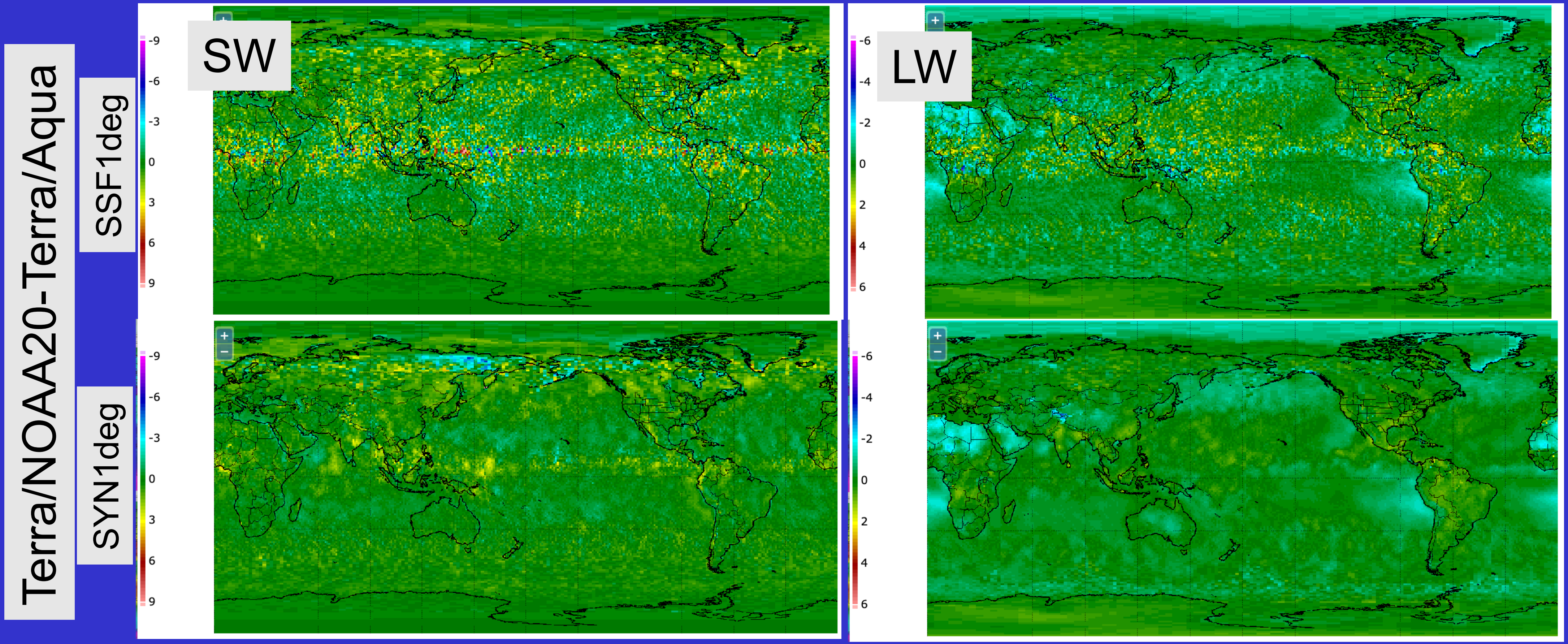
(Std/sigma)

SYN1deg

N20-Aqua	Global bias	Std of regional biases	N20 Global mean	Regional sigma
SW all	0.3620	1.2009	90.0	37.9 (3.2%)
LW all	-0.2071	0.8086	242.2	36.7 (2.2%)

- Note that the N20 – Aqua SSF1deg and SYN1deg global biases are similar
- The standard deviation of the regional biases (std) indicate that the SSF1deg noise is twice that of SYN1deg
- The SYN1deg N20-Aqua regional bias noise is 3.2% and 2.2% of the natural regional all-sky SW and LW flux variability, respectively

Terra/NOAA20 – Aqua/Terra SSF1deg & SYN1deg August 2019



- The Terra/N20 – Terra/Aqua SSF1deg and SYN1deg regional SW and LW all-sky biases are similar, and are smaller than the single satellite products

Terra/NOAA20 – Aqua/Terra SSF1deg & SYN1deg August 2019

SSF1deg

Terra/N20- Terra/Aqua	bias	Std of regional biases	Terra/N20 Global mean	Regional sigma
SW all	0.1455	1.1854	89.5	37.7 (3.2%)
LW all	-0.1227	0.6162	243.4	36.5 (1.7%)

SYN1deg

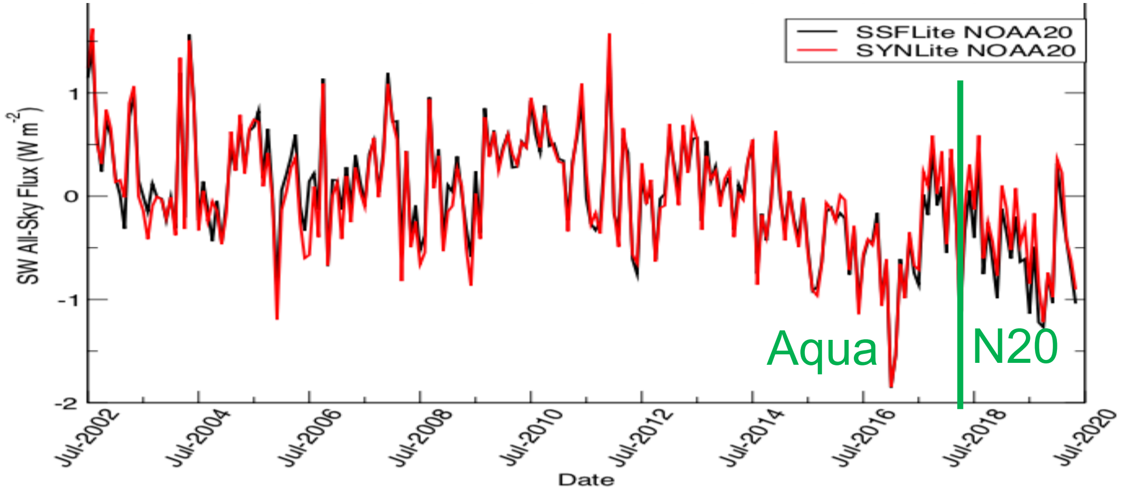
Terra/N20- Terra/Aqua	bias	Std of regional biases	Terra/N20 Global mean	Regional sigma
SW all	0.1794	0.6324	89.9	37.6 (1.7%)
LW all	-0.1242	0.4000	243.0	36.5 (1.1%)

- Note that the Terra/N20 – Terra/Aqua SSF1deg and SYN1deg global biases are similar
- By adding Terra the SSF1deg and SYN1deg global bias and regional standard deviation is about half

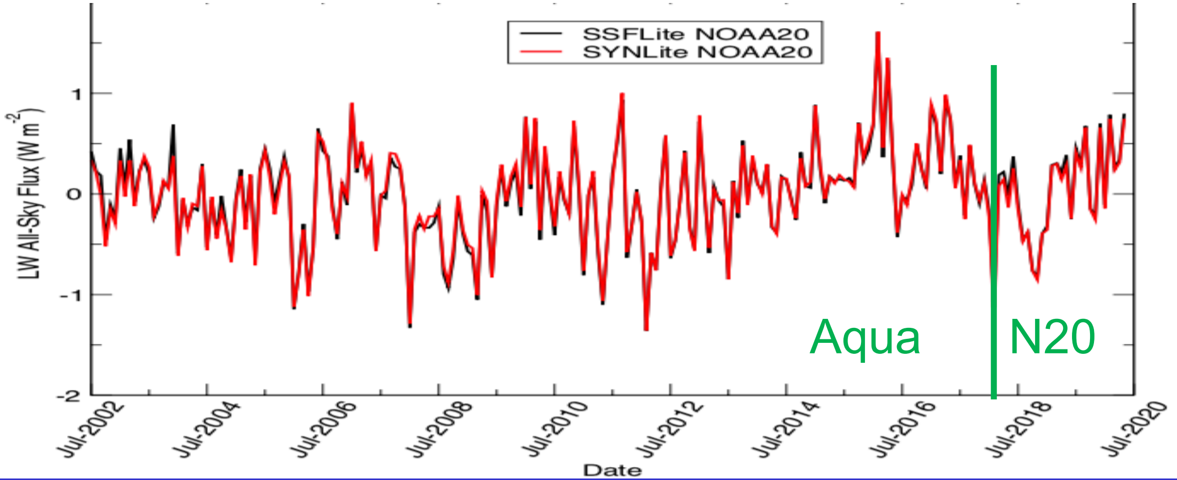
SSF1deg and SYN1deg global mean anomalies

Append the N20 global means beginning in May 2018 with the Aqua global means
Take the anomaly

SSF1deglite and SYN1deglite N20 SW comparison



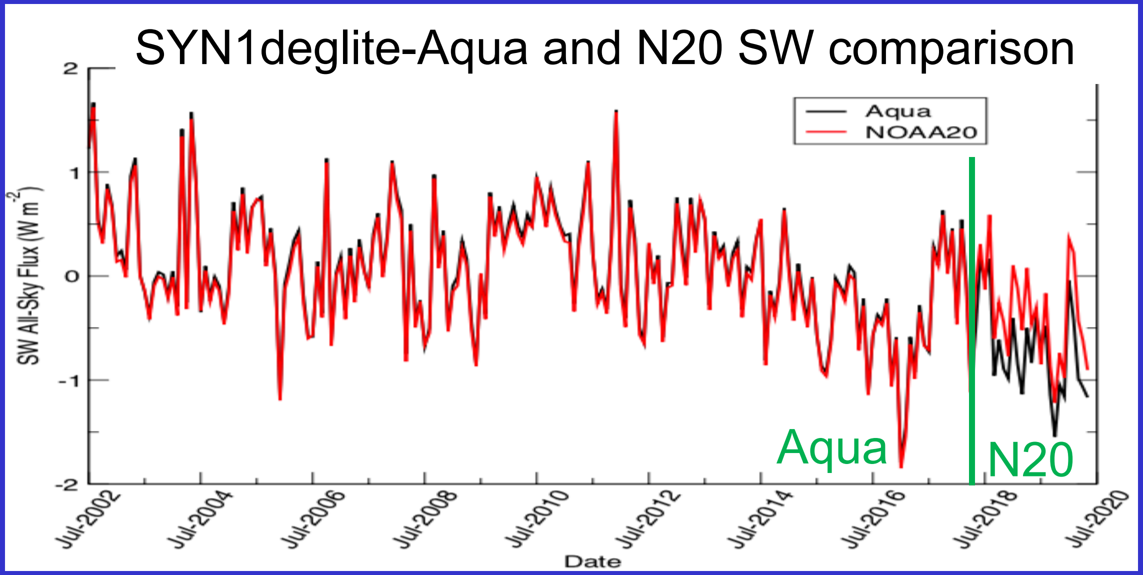
SSF1deglite and SYN1deglite N20 LW comparison

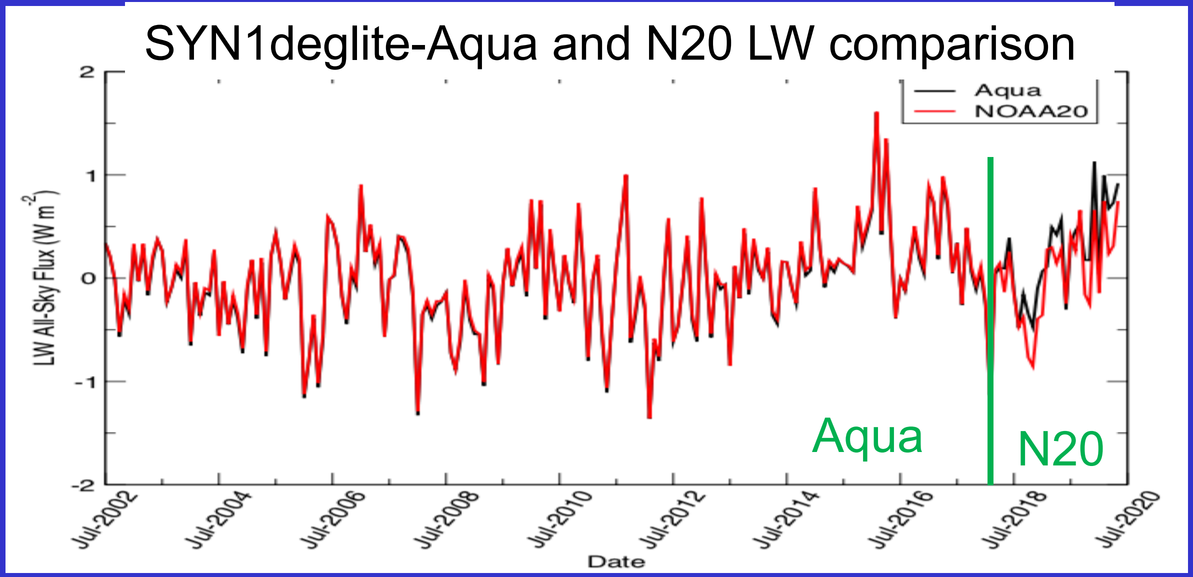


- The SSF1deglite and SYN1deglite global all-sky LW and SW anomalies are similar indicating that the TISA temporal interpolation methods are robust

N20 and Aqua SYN1deg global mean anomalies

Append the N20 global means beginning in May 2018 with the Aqua global means and compare with the Aqua 2002-2020 global means





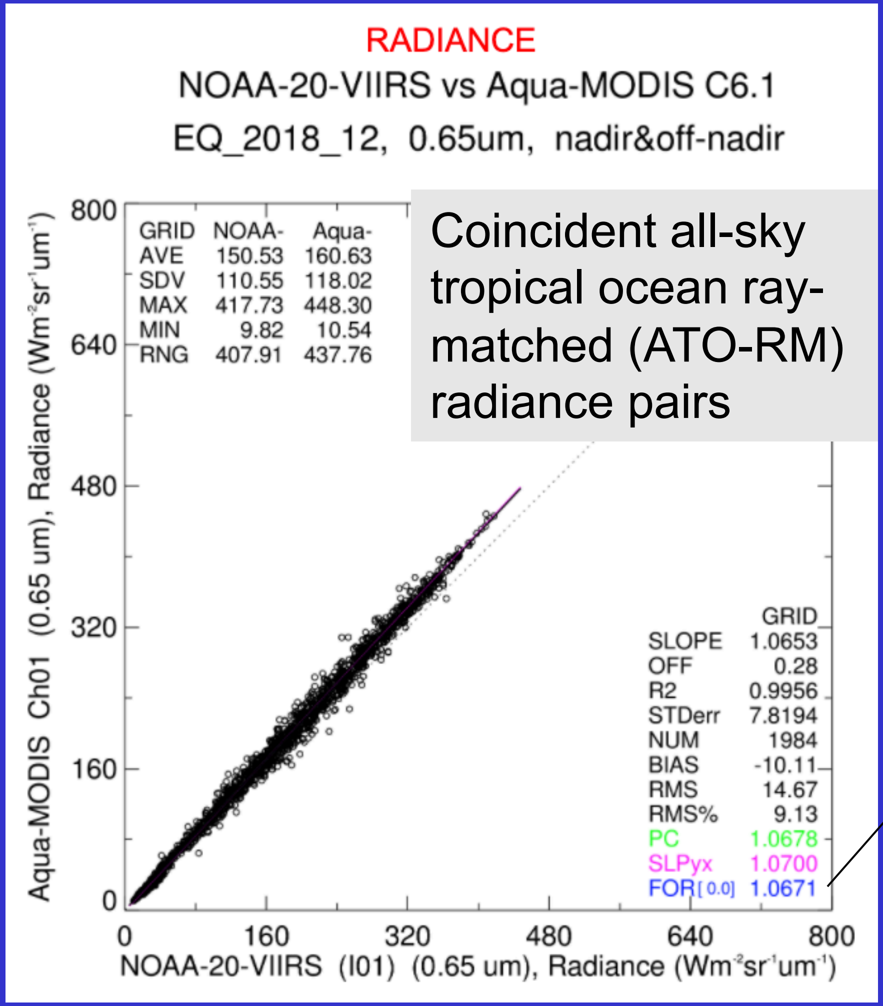
- The N20 global all-sky SW and LW flux means seem to smaller and larger than Aqua, respectively
- We are looking into this

GEO and imager CALIBRATION

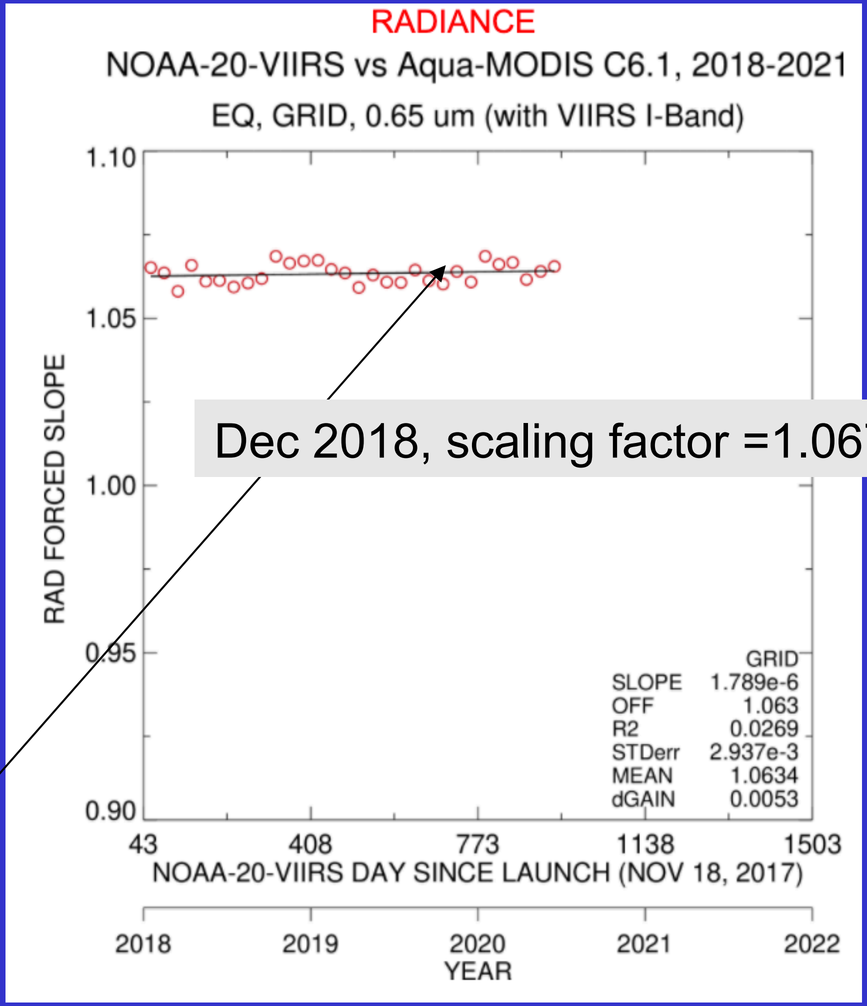
Migrating the GEO calibration reference from Aqua-MODIS to NOAA20 VIIRS

- Need to have a seamless transition when inter-calibrating GEOs with Aqua-MODIS or NOAA-20 VIIRS in order to maintain consistent clouds and GEO derived broadband fluxes
- Radiometrically scale the NOAA-20 VIIRS C2 channel radiances to Aqua-MODIS C6.1 using coincident all-sky tropical ocean ray-matched (ATO-RM) radiance pairs
- Apply the scaling factors to the NOAA-20 VIIRS C2 channel radiances.
- Inter-calibrate GEO/Aqua-MODIS and GEO/N20-VIIRSscaled using ATO-RM
- Compare the GEO gains based from Aqua-MODIS and N20-VIIRSscaled. They should be the same.

NOAA-20 VIIRS and Aqua-MODIS ATO-RM 0.64 µm inter-calibration



Coincident all-sky tropical ocean ray-matched (ATO-RM) radiance pairs

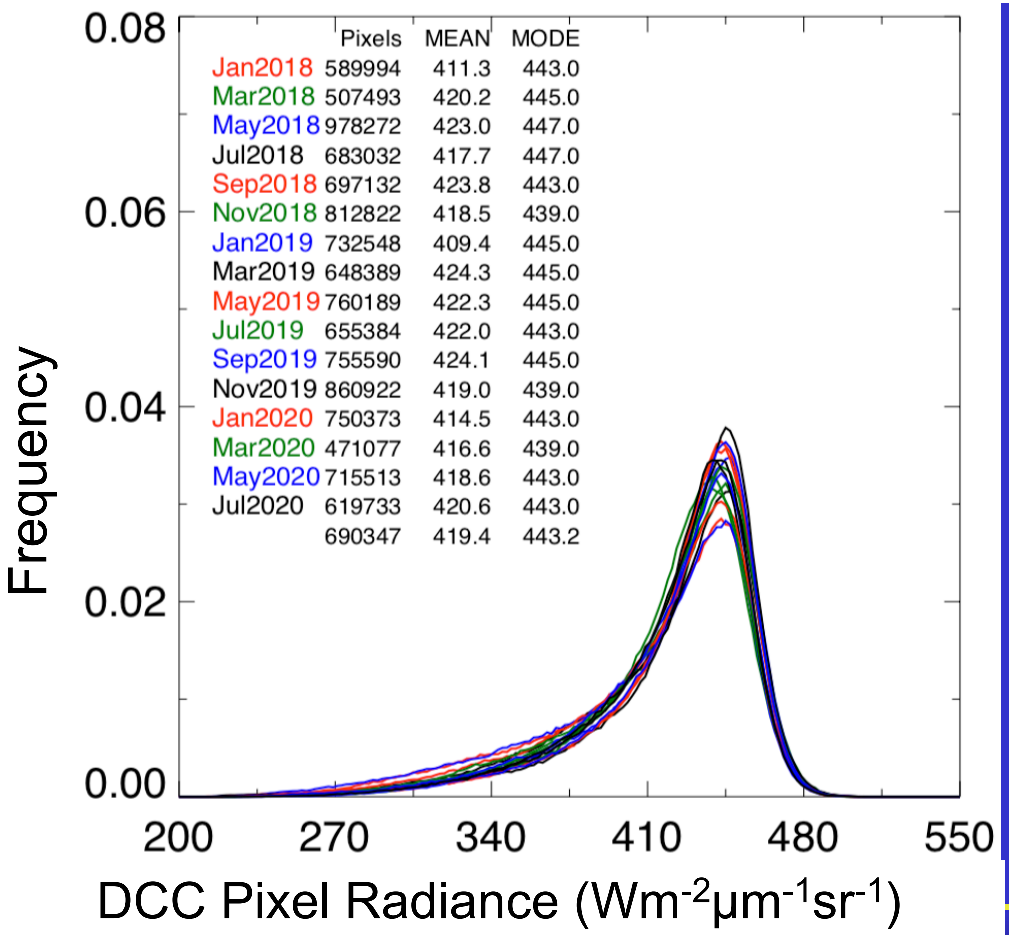


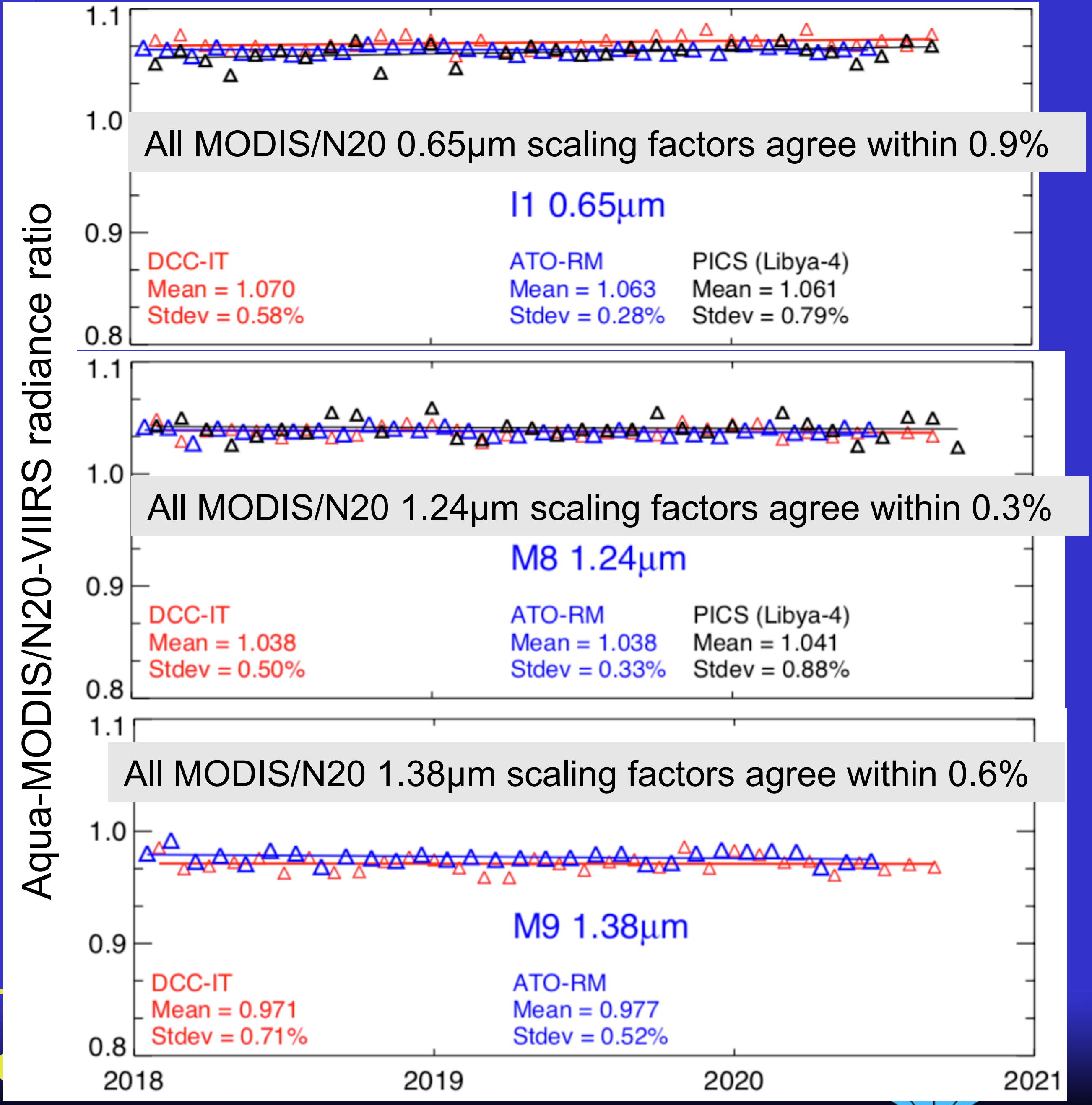
Dec 2018, scaling factor =1.0671

The Aqua-MODIS C6.1 B1 and NOAA20-VIIRS C2 I01 calibration timeline difference is 1.0634

Comparison of MODIS/VIIRS inter-calibration methods

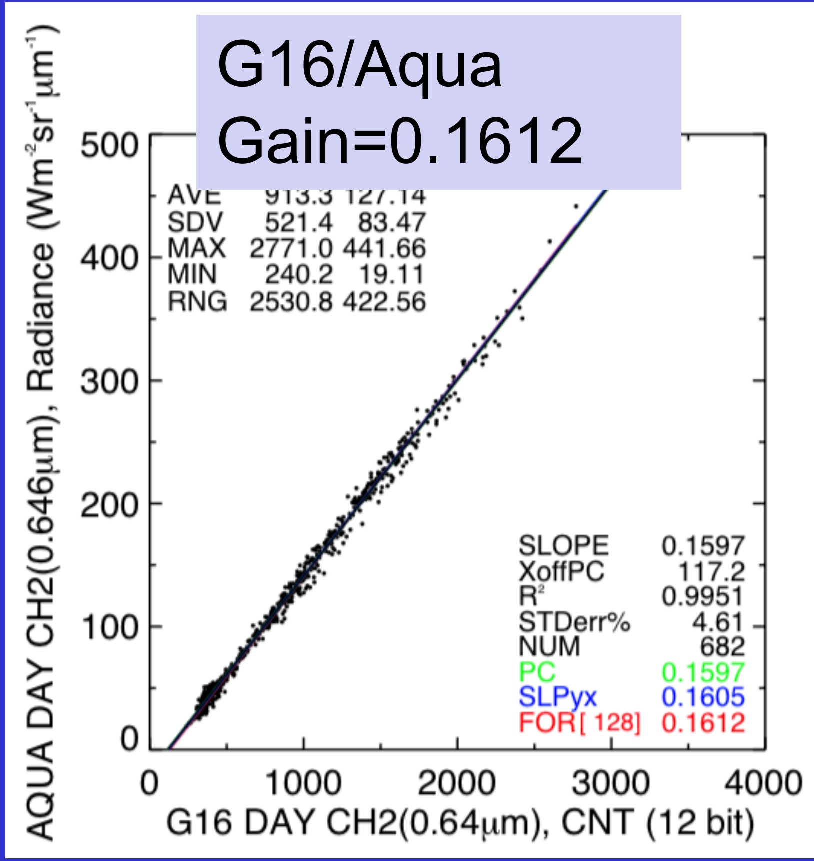
N20 VIIRS I01 Deep Convective Cloud (DCC) reflectances

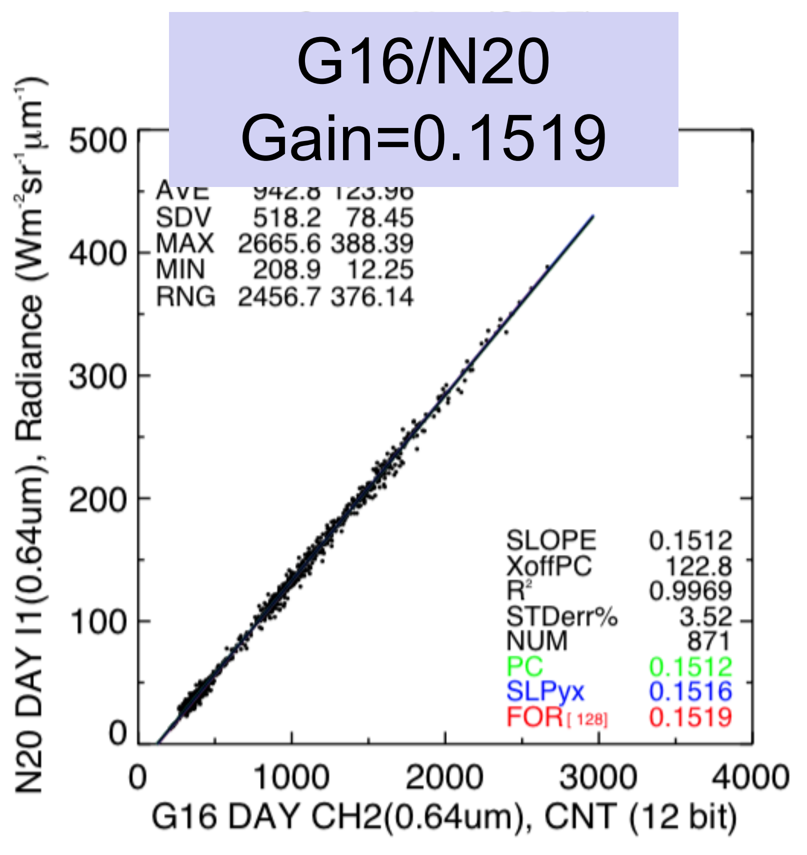


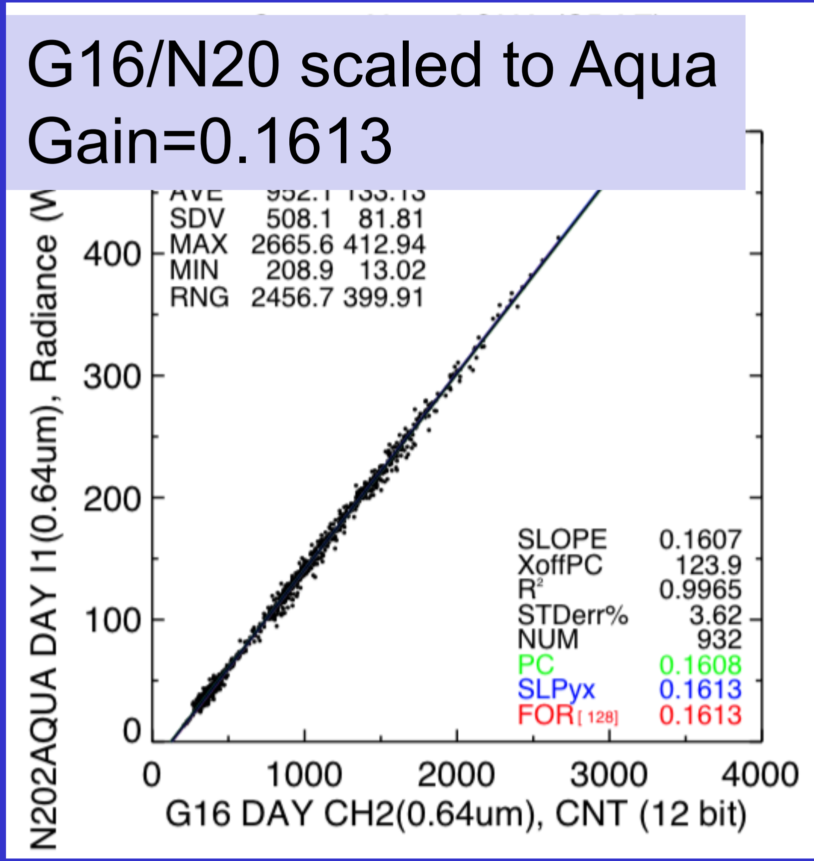


Ratio the N20-VIIRS and Aqua-MODIS DCC reflectances to compute scaling factor

G16/Aqua and G16/N20 January 2020 scatter plot comparison

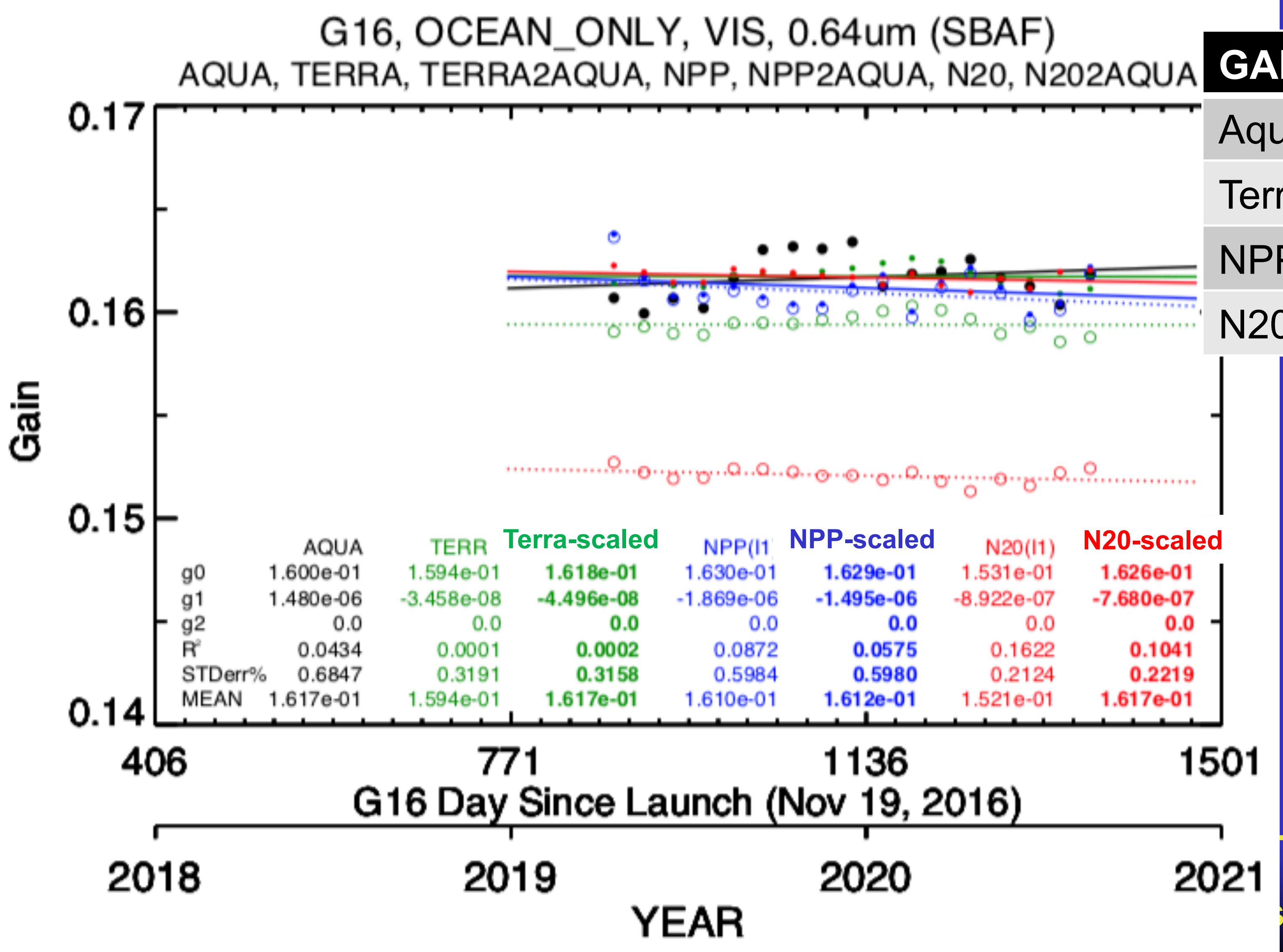






- The G16/N20 gain is 0.1519 and is -5.8% lower when compared to the Aqua gain of 0.1612
- After apply the N20/Aqua radiometric scaling factor, the Aqua and N20(scaled to Aqua) gain difference is +0.1%
- We can now use N20(scaled to Aqua) as the forward processing imager and maintain the Aqua calibration reference

GOES-16 gain comparison



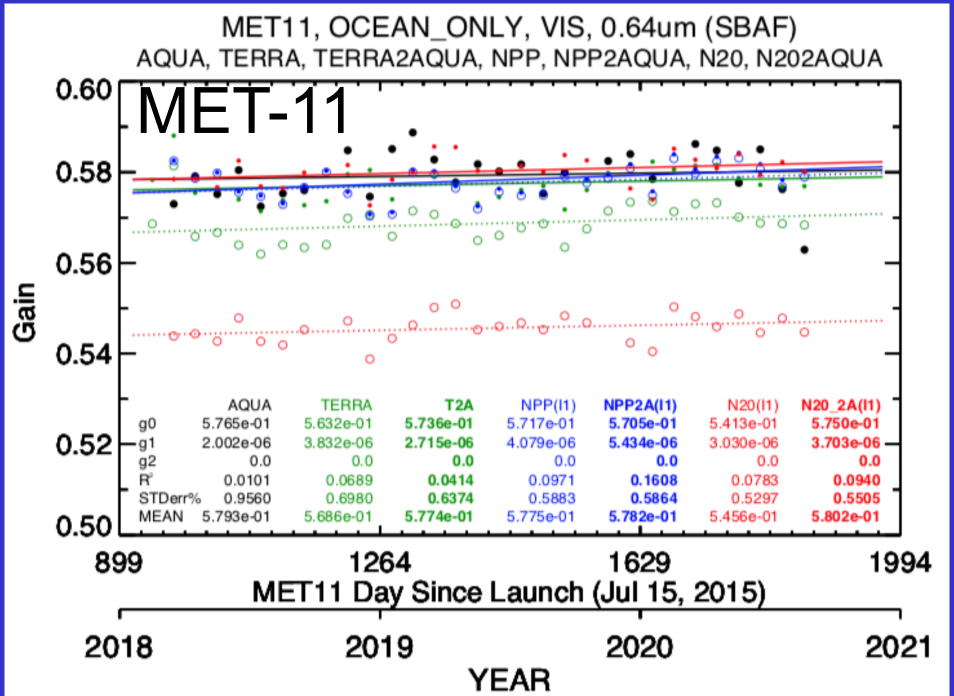
GAIN	unscaled	Scaled to Aqua
Aqua	0.1617	0.1617
Terra	0.1594 (-1.4%)	0.1617 (0.0%)
NPP	0.1610 (-0.4%)	0.1612 (-0.3%)
N20	0.1521 (-5.9%)	0.1617 (0.0%)

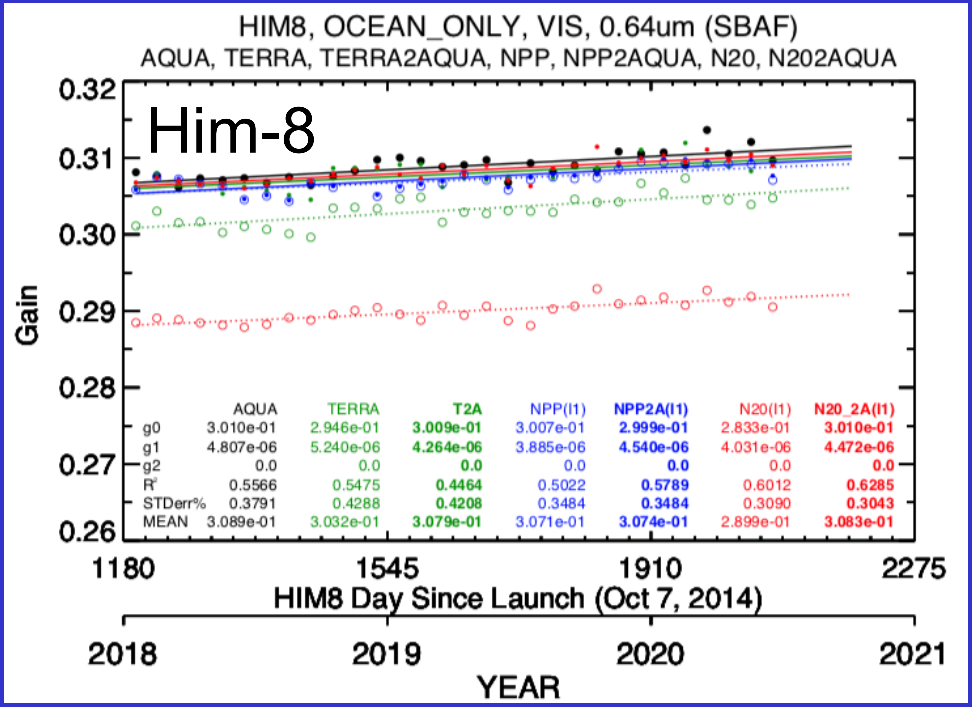
Compare dotted line (unscaled) with solid line (scaled to Aqua) with Aqua (solid black line)

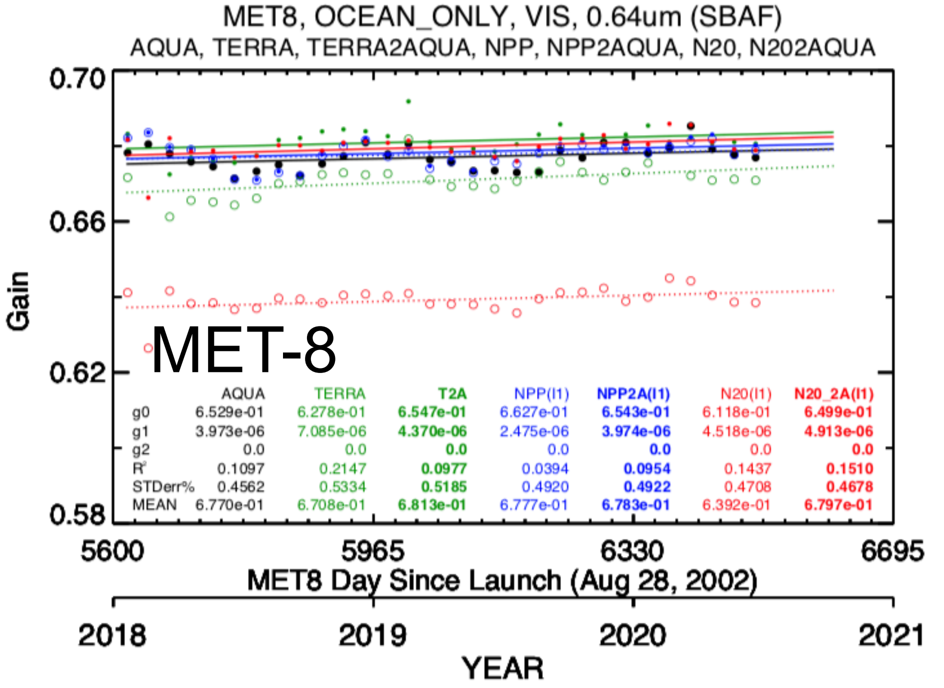
- The Aqua/N20 ATO-RM calibration difference was 1.0631 and very close to the 5.9% based on GOES-16

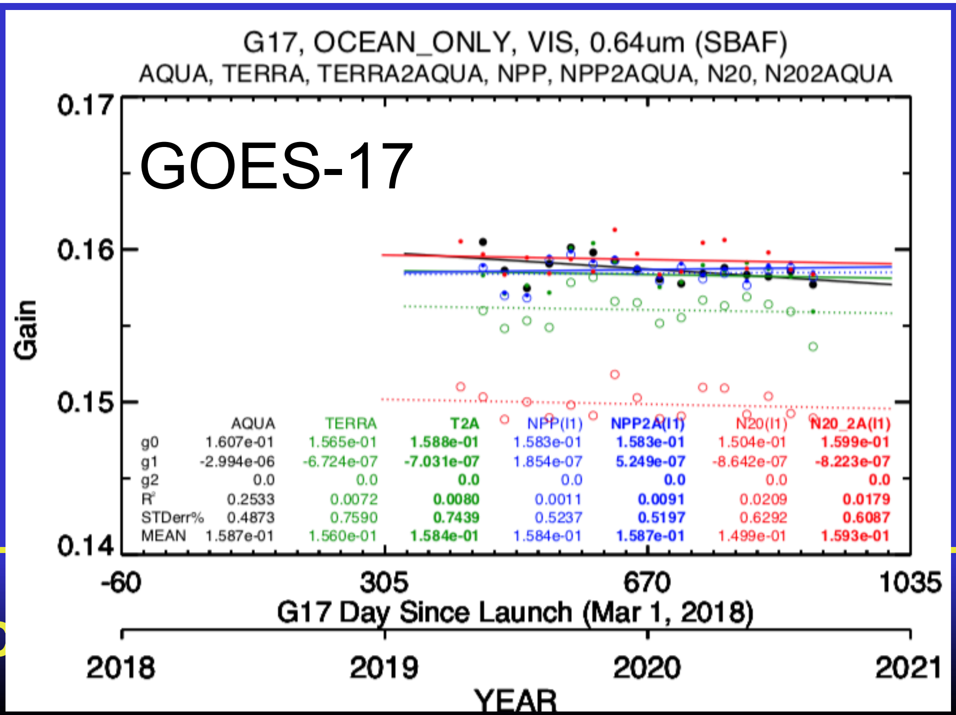
GEO gain comparisons

- All 5 GEOs show that N20-scaled is closer to the Aqua reference calibration than the N20 (unscaled)









GEO scaling validation

	N20	N20 Scaled to Aqua	stderr
G-16	-5.9%	+0.0%	±0.6%
G-17	-5.5%	+0.4%	±0.5%
Him-8	-6.5%	-0.2%	±0.4%
Met-8	-5.6%	+0.4%	±0.5%
Met-11	-5.8%	+0.2%	±1.0%
Aqua	-6.3%		±0.3%

	NPP	NPP Scaled to Aqua
G-16	-0.4%	-0.3%
G-17	-0.2%	+0.0%
Him-8	-0.6%	-0.5%
Met-8	+0.1%	+0.2%
Met-11	-0.3%	-0.2%
Aqua	-0.2%	

	Terra	Terra Scaled to Aqua
G-16	-1.4%	+0.0%
G-17	-1.7%	-0.2%
Him-8	-1.8%	-0.3%
Met-8	-0.9%	+0.6%
Met-11	-1.8%	-0.3%
Aqua	-1.6%	

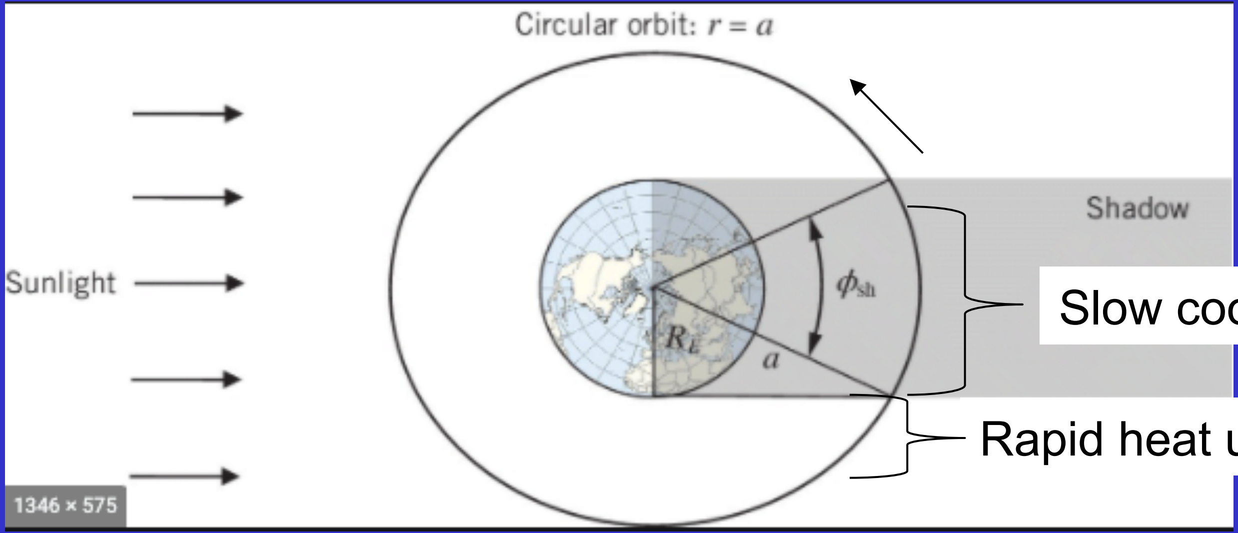
- The Aqua/N20, Aqua/NPP, and Aqua/Terra ATO-RM radiometric scaling factors were applied to the forward processing imager during GEO inter-calibration and compared with the GEO/Aqua gains
- The N20, NPP, Terra scaled to Aqua gave similar GEO gains as if they were scaled to Aqua directly
- The CERES GEO and Imager calibration group is ready to calibrate the GEO sensor record with any forward processing imager while maintaining the Aqua-MODIS calibration reference
- **If N20 was not scaled the visible calibration would be off by 6.3%, which would give very unreliable GEO cloud properties and will not be consistent with Aqua-MODIS**

KD tree

GOES-17 nighttime IR imagery degradation

- GOES-17 has a heat loop pipe issue. At night when the satellite is behind the Earth near the Earth's shadow is when the focal plane is heats up
- This causes degraded nighttime IR imagery between 10:30-16:30 GMT. The cloud retrievals cannot be performed using these images making them unusable
- The 3.8µm and 10.7µm are not degraded and are used to reconstruct the remaining IR channels at night using KD tree.
  - The reconstructed IR imagery is used to retrieve clouds
  - The reconstructed water vapor and window channel is used to derive the GEO LW fluxes
- In order to test the KD tree clouds and fluxes, GOES-16 March 2020 clouds and fluxes are used. GOES-16 does not have the heat loop pipe issue and is a copy of GOES-17
  - KD tree clouds and fluxes are compared against the GOES-16 retrieved clouds and fluxes
  - TISA temporal interpolation is applied across the 6 hours of missing data and is also compared to the GOES-16 retrieved clouds and fluxes

Seasonal variation of the GOES-17 IR imagery degradation

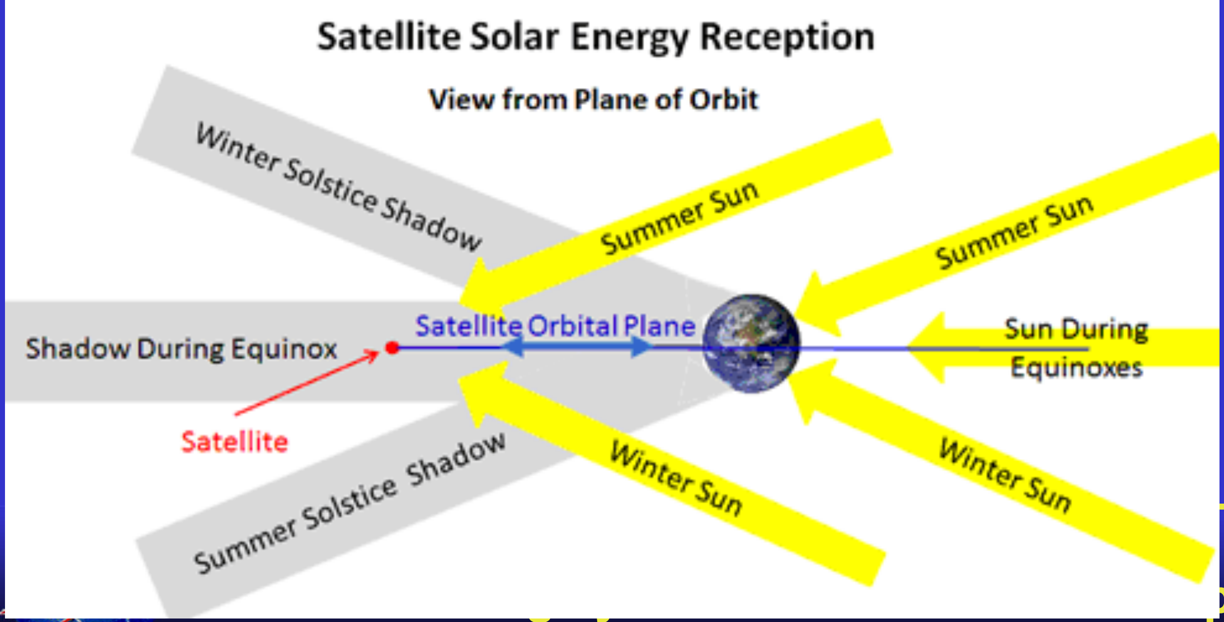


Due to the baffling on the GEO satellite only the hours before shadow are impacted

Slow cool down of the focal plan

Rapid heat up of the focal plan

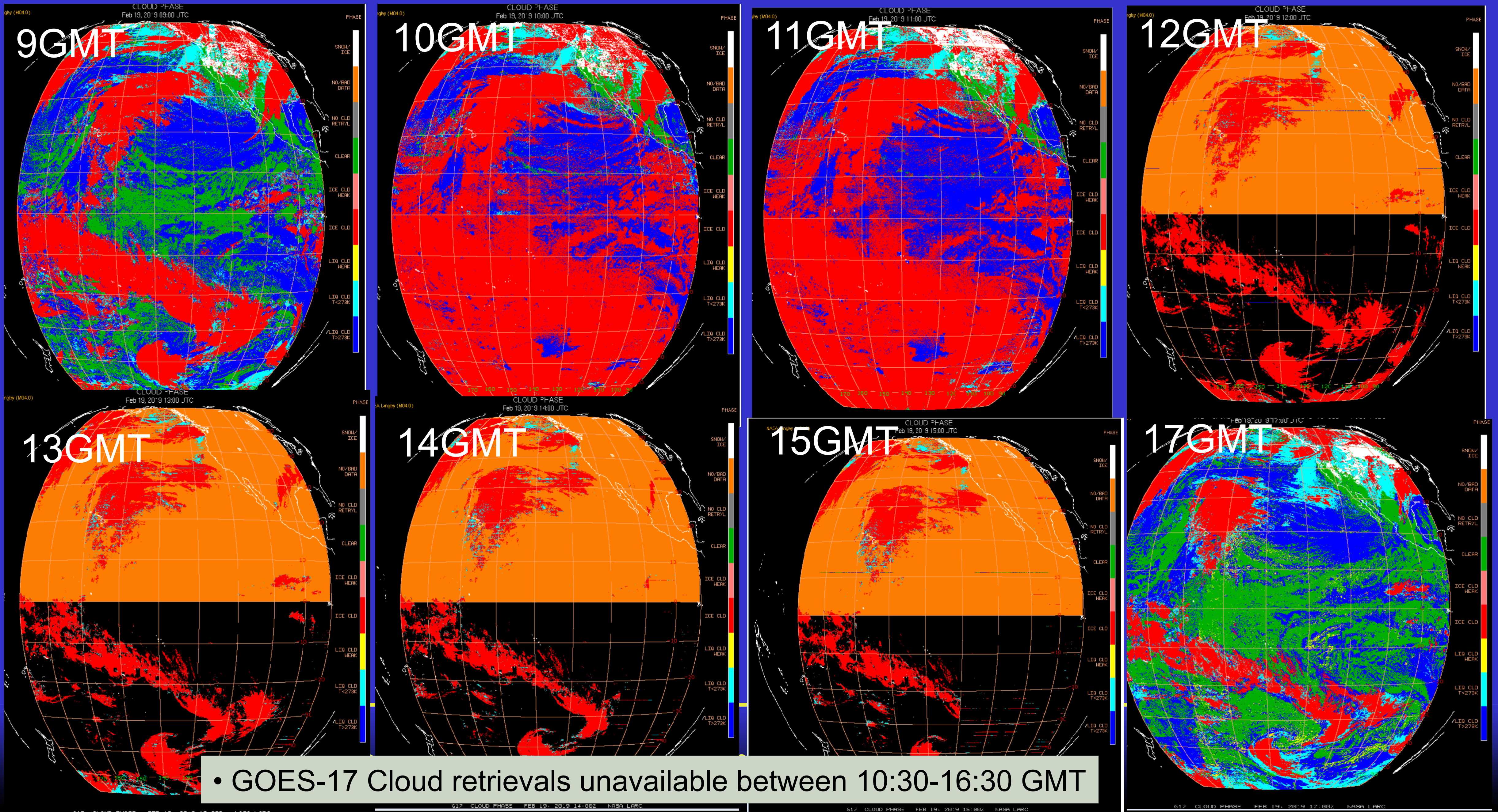
About 6 hours impacted



The GEO orbit plane is located at the Equator

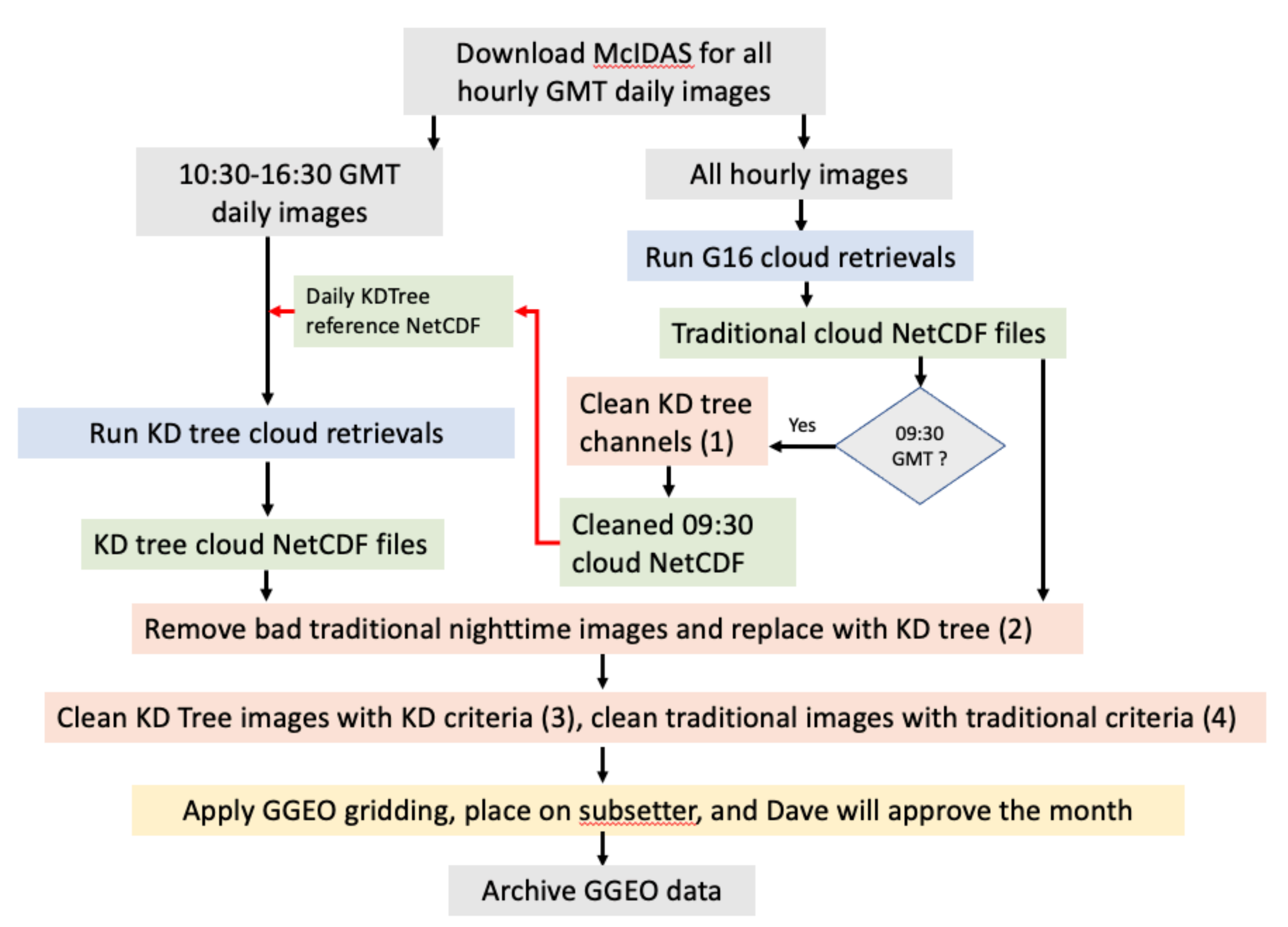
During the equinox the solar plane and the GEO plane overlap and is when most of the IR imagery is impacted

GOES-17 Cloud phase, Feb. 19, 2018



- GOES-17 Cloud retrievals unavailable between 10:30-16:30 GMT

GOES-17 KD tree flowchart implementation



1) Select the best daily image prior or at 9:30 GMT , If 9:30 GMT is suspect try 9:00 GMT using the SATCORP web site
2) Replace all GOES-17 10:30 GMT and 16:30 GMT images with Kdtree reconstructed images
3) Ensure no bad scanlines in 3.9 µm and 10.4 µm channels. If bad scanline exists in either, remove same scanline in all other KD Tree reconstructed images
4) Traditional spurious image criteria to detect spurious scan lines and other image features

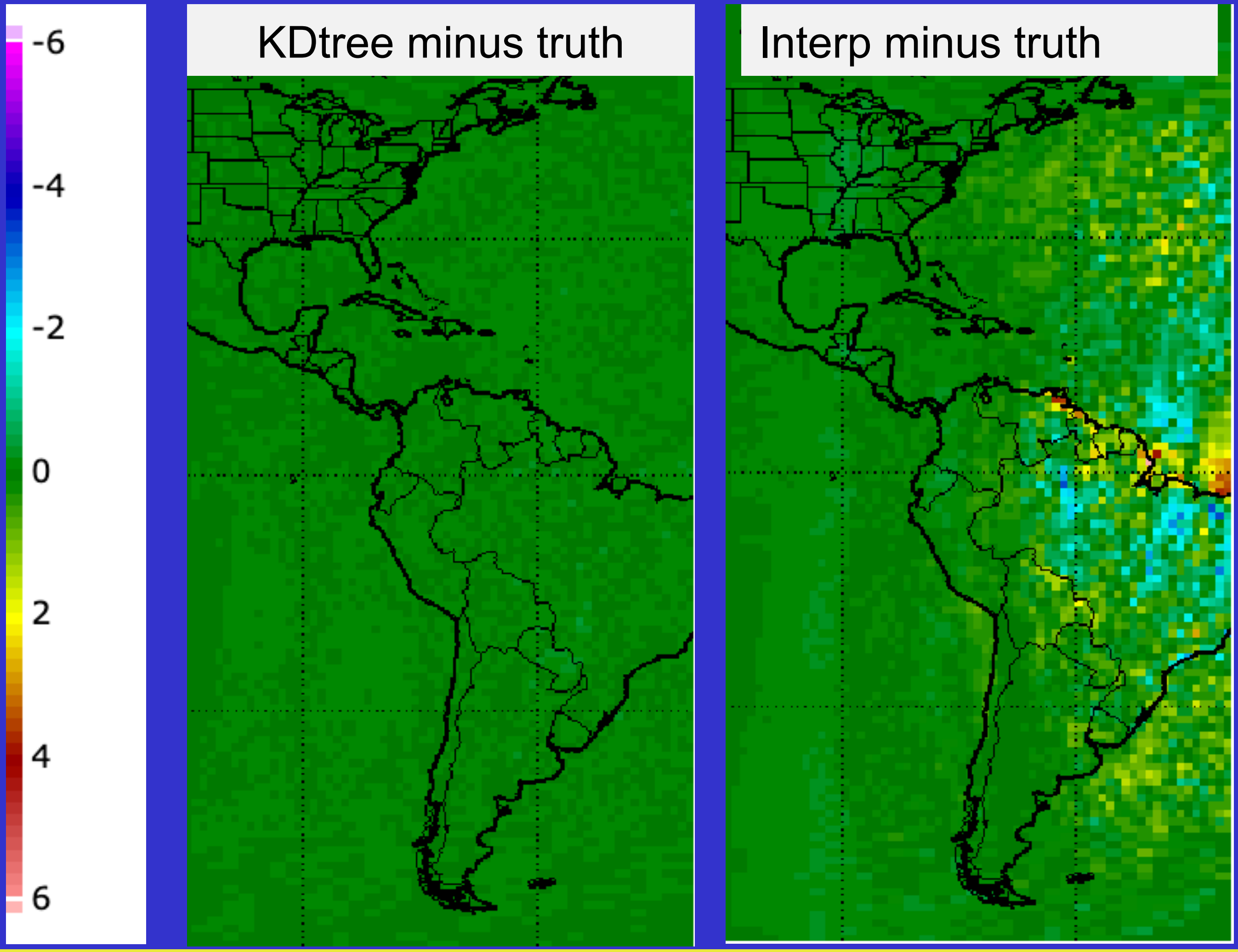
SYN1deg GOES-16 all-sky SW flux (Wm-2), March 2020

- GOES-16 Training image 5:30 GMT

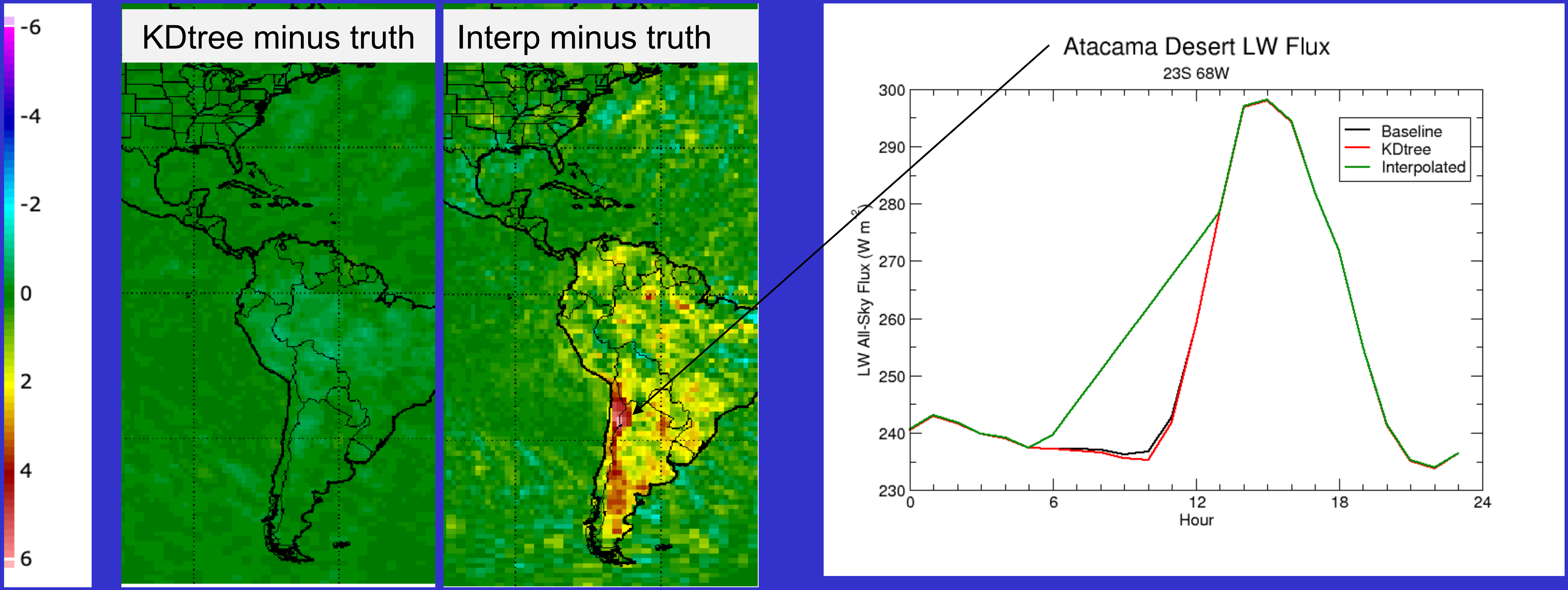
- Apply KD tree between 6:30 GMT and 12:30 GMT (these are the same local hours of GOES-17 degraded imagery)

- TISA interpolation is applied between 5:30 GMT and 13:30 GMT

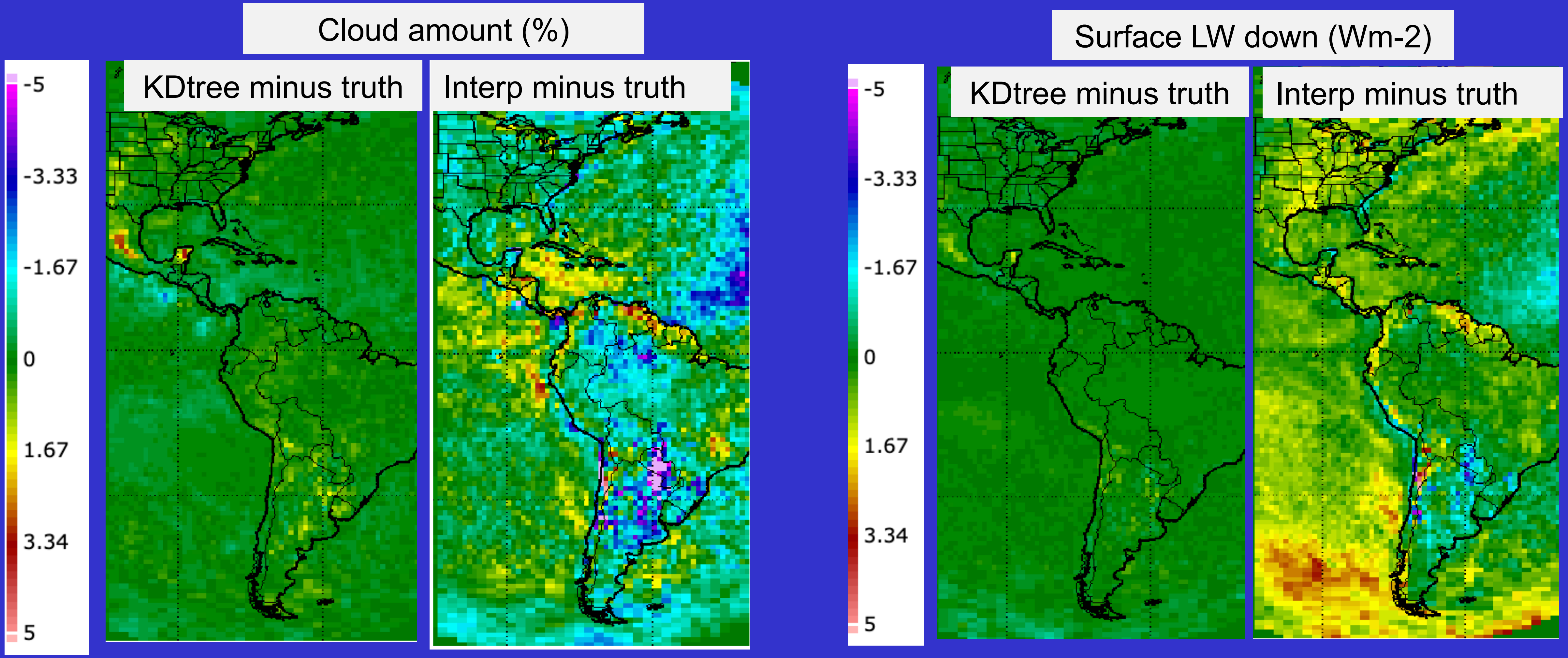
- Truth are the GOES-16 IR full channel retrievals



SYN1deg GOES-16 all-sky LW flux (Wm-2), March 2020



SYN1deg GOES-16 cloud amount and surface LW flux down, March 2020



KD tree and interp comparison of SYN1deg GOES-16 March 2020

GOES-16 domain	KD tree bias	KD tree regional sigma	Interpolation bias	Interpolation regional sigma
All-sky SW obs	-0.003	0.040	0.060	0.488
All-sky LW obs	-0.034	0.147	0.436	0.738
computed				
All-sky SW TOA	0.002	0.066	-0.333	0.623
All-sky LW TOA	0.020	0.082	0.197	0.568
All-sky SWup	-0.001	0.020	0.042	0.105
All-sky SWdn	0.004	0.085	0.412	0.744
All-sky LWup	-0.063	0.187	0.018	0.628
All-sky LWdn	-0.004	0.152	0.483	0.895
clouds				
Cloud amount	-0.008	0.271	-0.478	1.180
Optical depth	0.001	0.060	0.187	0.267
Effective press	1.138	1.820	-1.195	6.995
Phase	-0.0004	0.0039	-0.0076	0.0150

- The Kdtree reconstructed IR imager is a vast improvement over TISA interpolation procedure

SW NB to BB

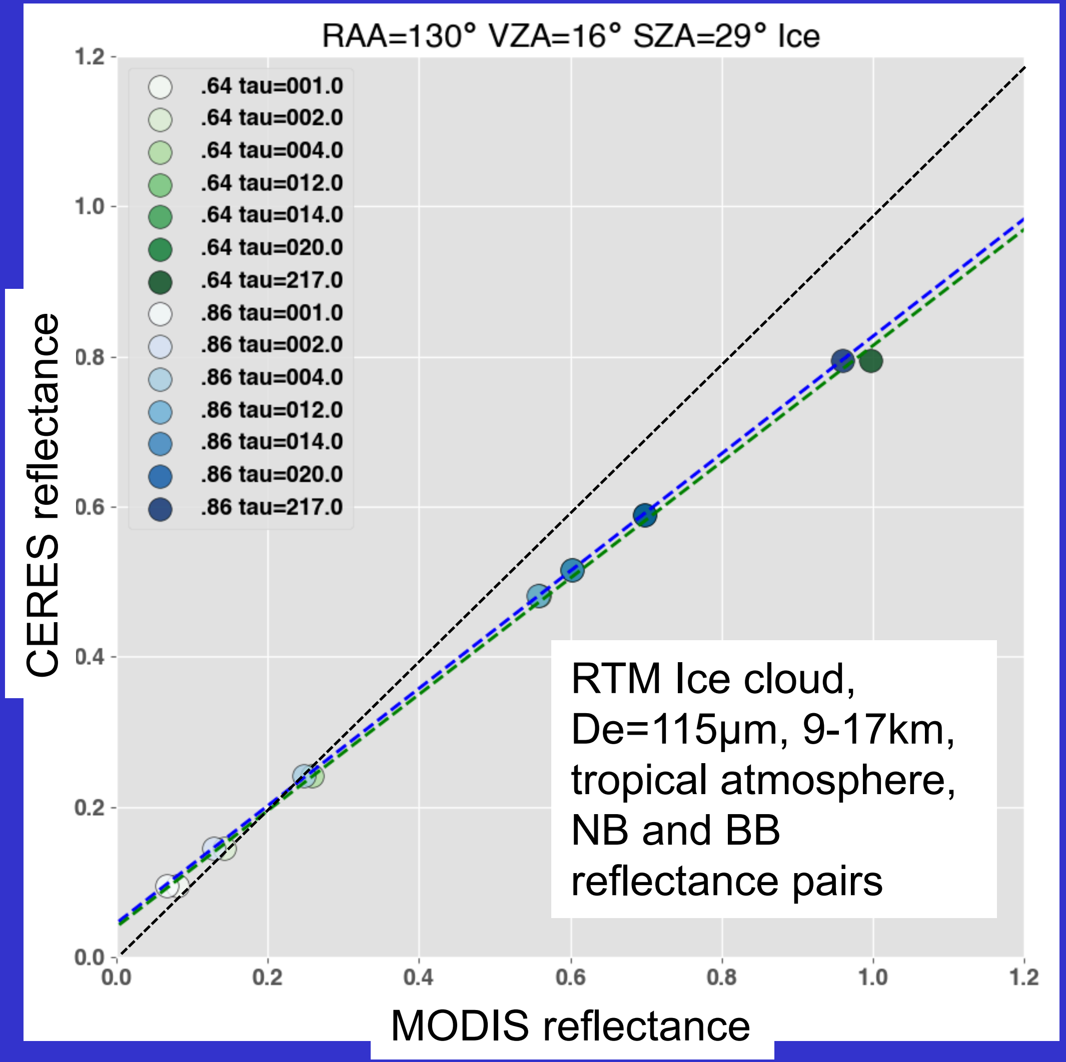
GEO SW NB to BB Ed5

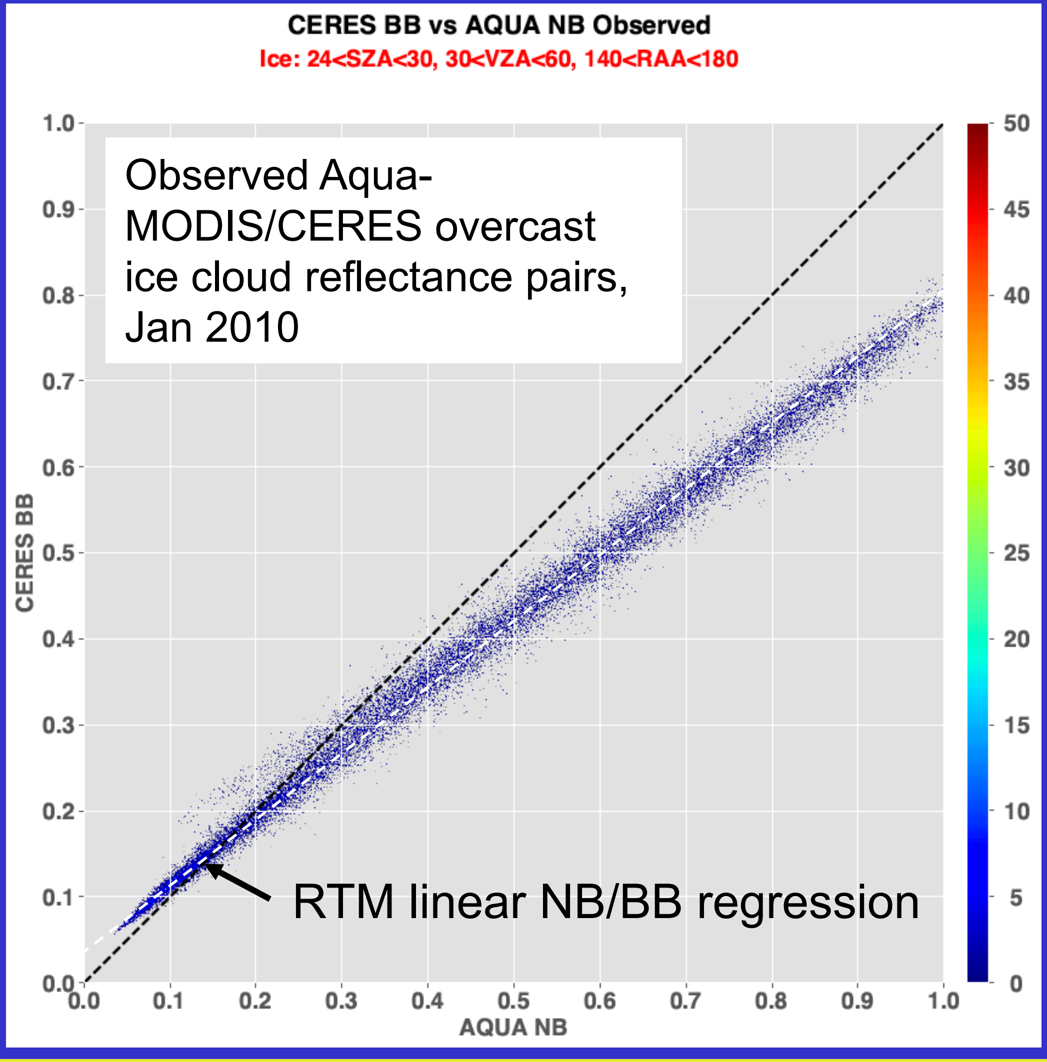
- Convert GEO visible narrowband (NB) channel directly to broadband (BB) radiance using hyper-spectral RTM, ~ 2500 wavelengths (0.2µm to 5µm)
  - Eliminate the Ed4 two step process of converting GEO to MODIS-like and then using empirical MODIS-like to BB radiance (Ed4 SW NB to BB LUT codes no longer exist)
  - Each GEO will have its own customized RTM LUT by convolving the RTM hyper-spectral radiances with the GEO spectral response function
- Continue to use the TRMM ADMs to convert BB radiance to flux
  - TRMM orbit precesses and provides complete solar zenith angle sampling
- Continue to inter-calibrate GEOs with Aqua-MODIS to maintain consistent calibration across GEO platforms in both space and time

SW NB to BB Validation Strategy and Summary So Far

- First validate with Aqua MODIS/CERES and TRMM VIRS/CERES data
  - Each sub-footprint NB radiance is individually converted to BB radiance using either the clear-sky ocean, water cloud, or ice cloud NB to BB LUT and combined subfootprint derived BB radiance is then compared to the CERES BB radiance
- Second apply to GEO NB fluxes and compare with coincident CERES fluxes
- The linear regression based on the optical depth bin NB and BB reflectances provided a more accurate BB reflectances than using the specified observed cloud optical depth bin
- The RTM 115μm ice and 50μm water particle size models best fit the MODIS 0.65 μm and 0.86μm observations
  - Perhaps the MODIS channel narrowband calibration differs from the RTM
- The RTM 32μm water and 115μm ice particle sizes models best matched the SCIAMACHY hyper-spectral reflectances
- The MODIS 0.65μm reflectances were more inline with the RTM than the 0.86μm

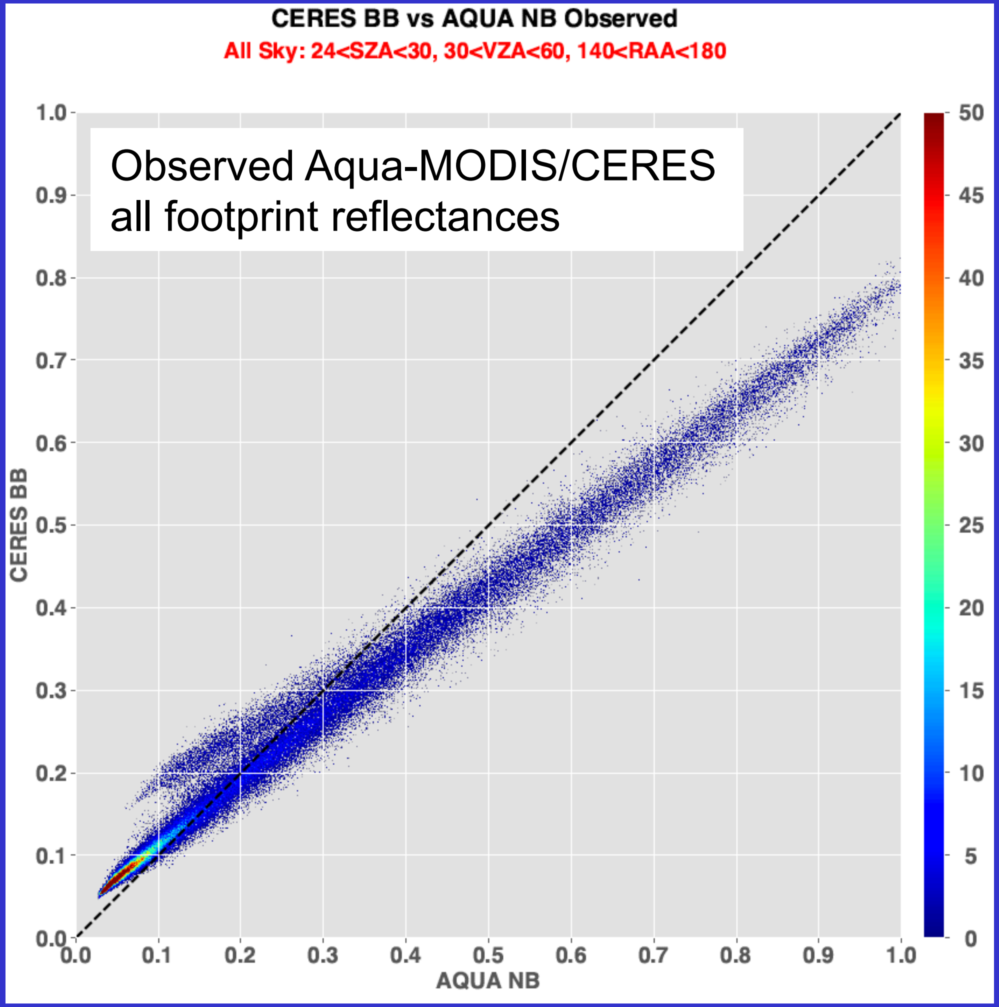
The NB/BB linear regression strategy

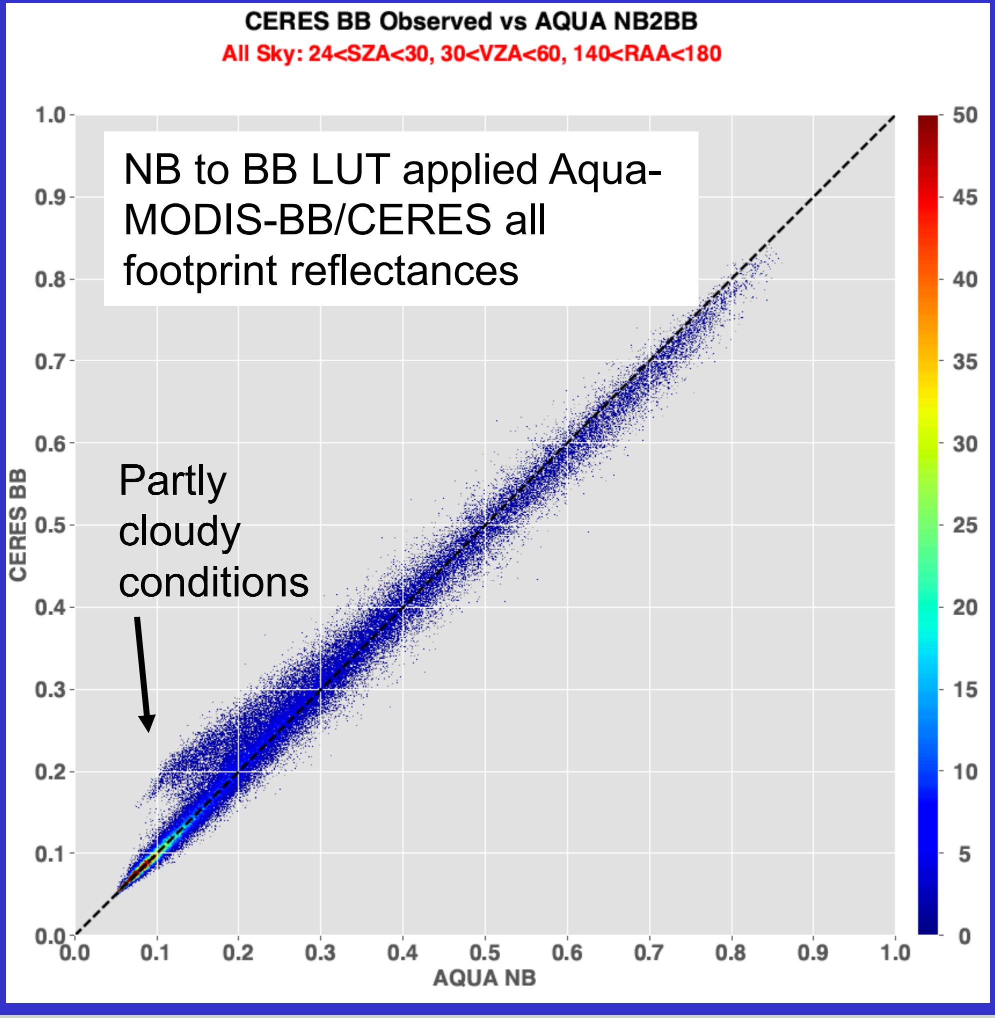




- The observed NB and BB ice cloud reflectance pairs show a linear distribution
- Rather than use the RTM specified optical bin, linearly regress the NB and BB reflectances to convert NB to BB

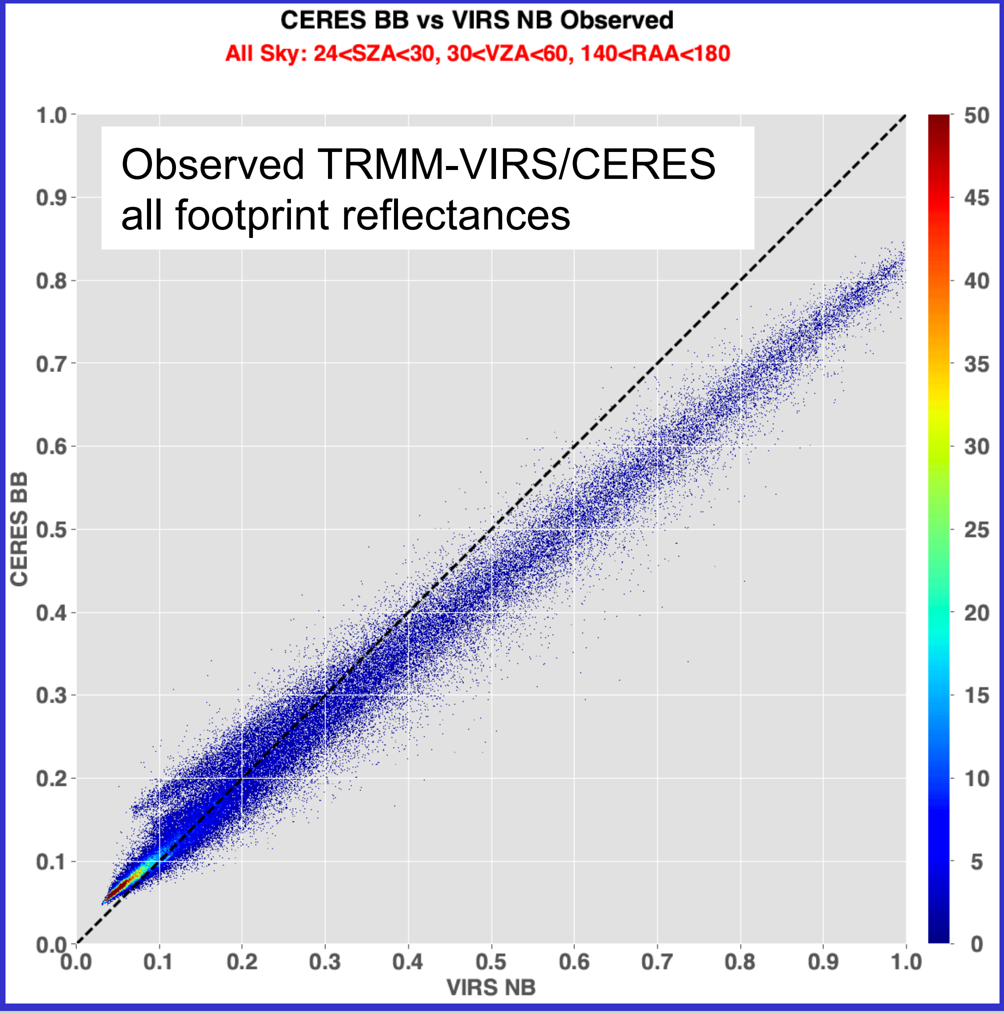
Aqua-MODIS/CERES NB/BB linear regression

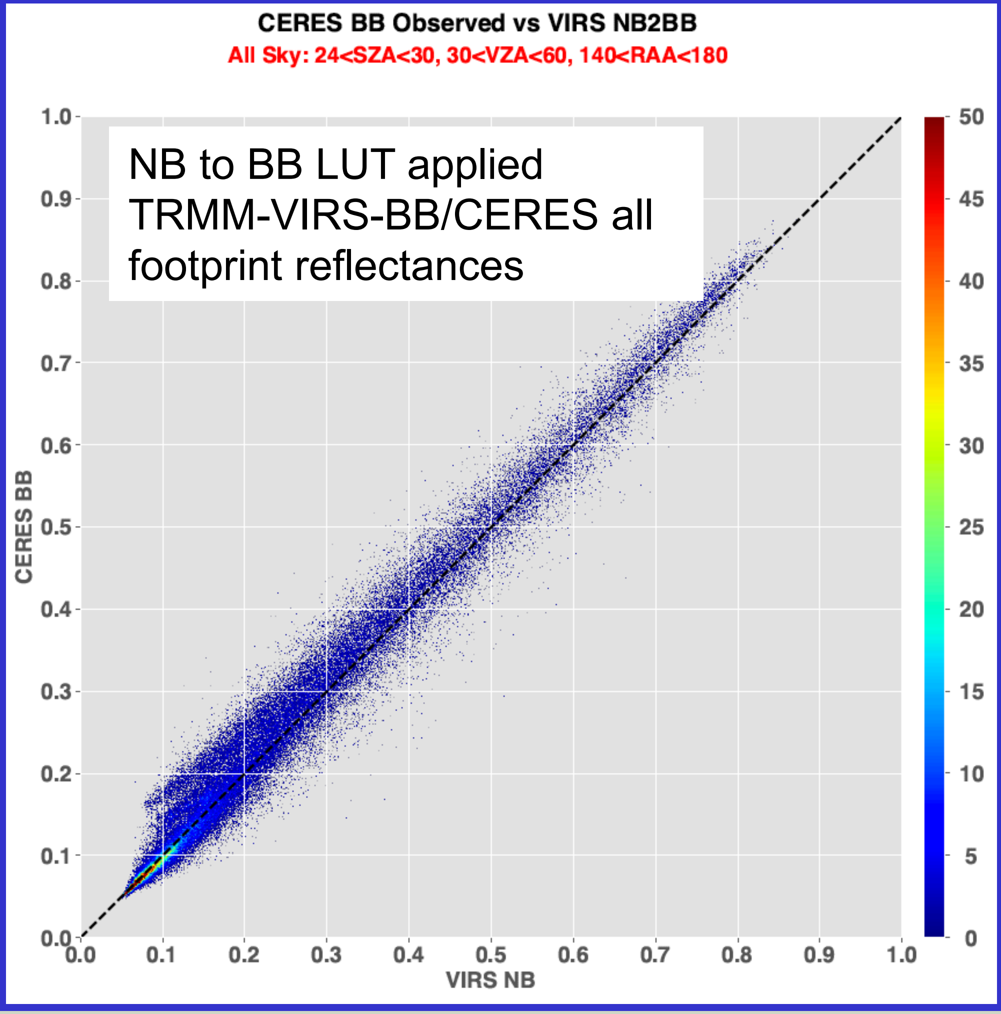




- The RTM accurately describes most all-sky footprint NB and BB reflectances, using the based on the subfootprint clear-sky ocean, ice and water clouds LUT
- Some partly cloud conditions need to be examined

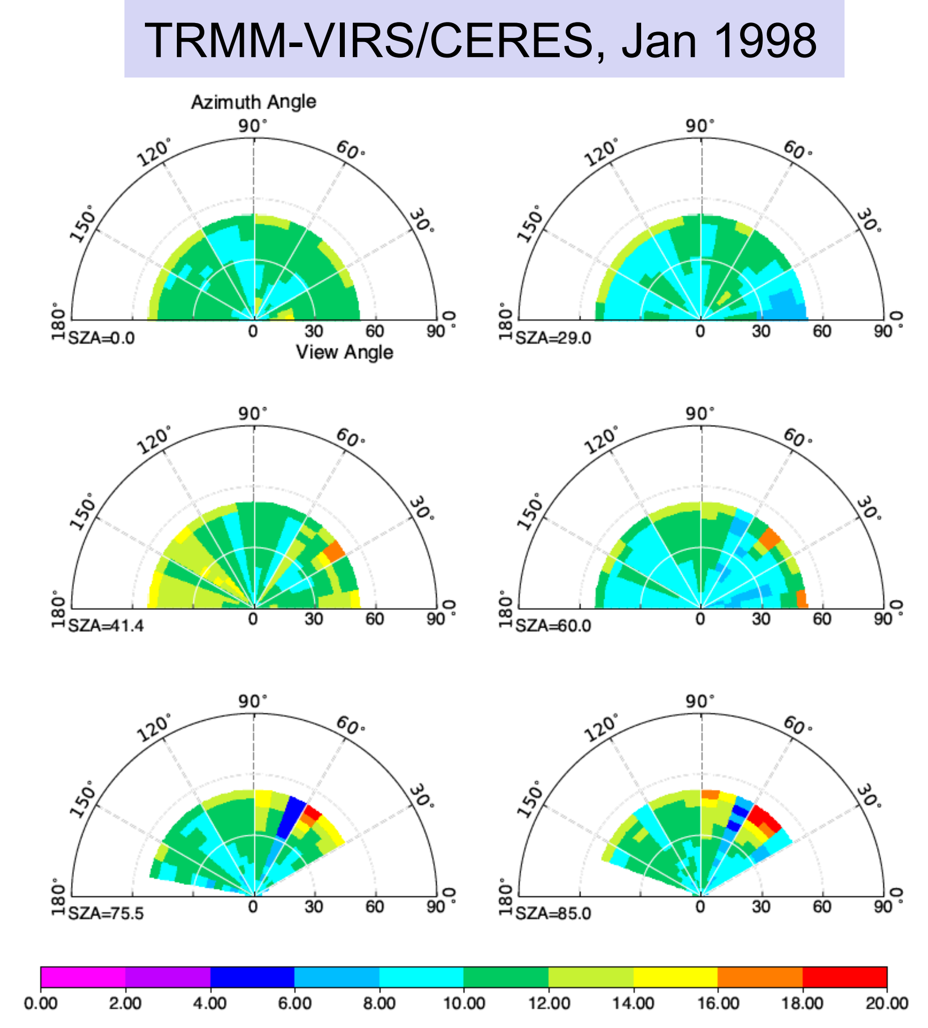
TRMM-VIRS/CERES NB/BB linear regression

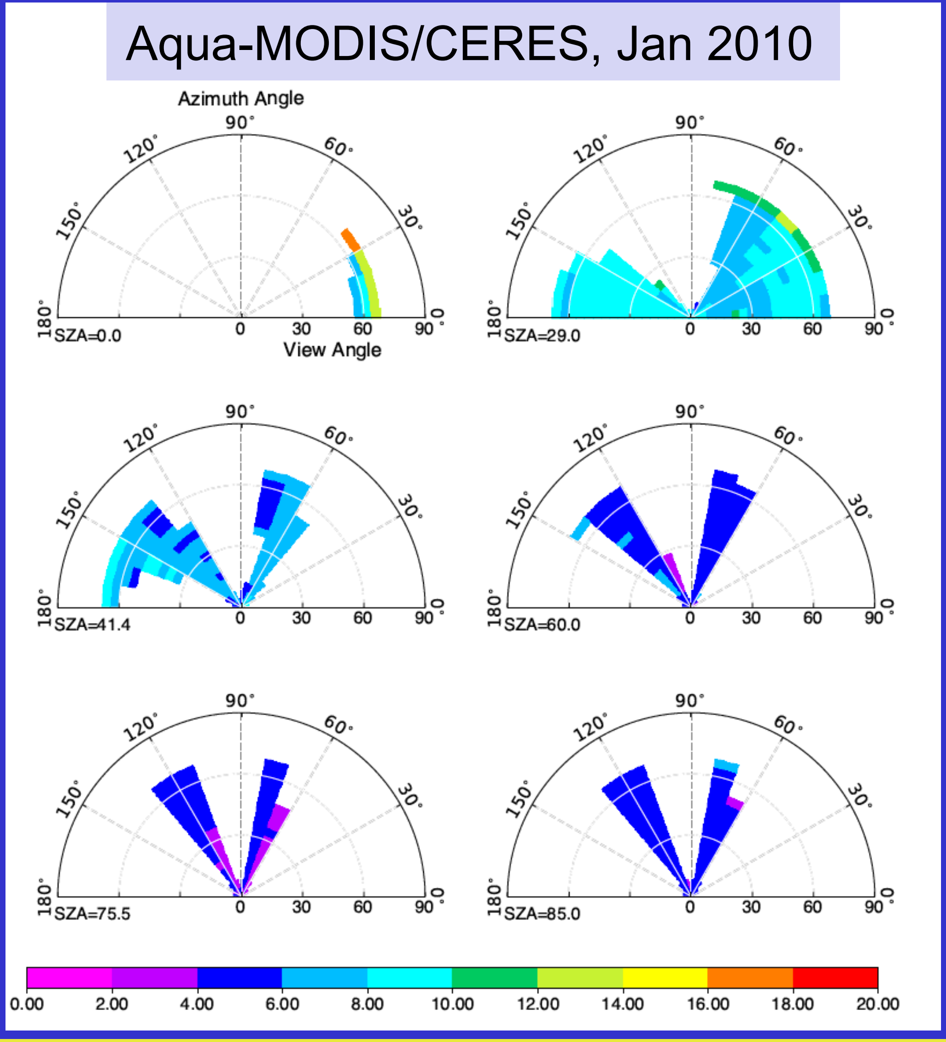




- The TRMM VIRS/CERES NB to BB reflectance pairs have greater scatter than the Aqua MODIS/CERES pairs

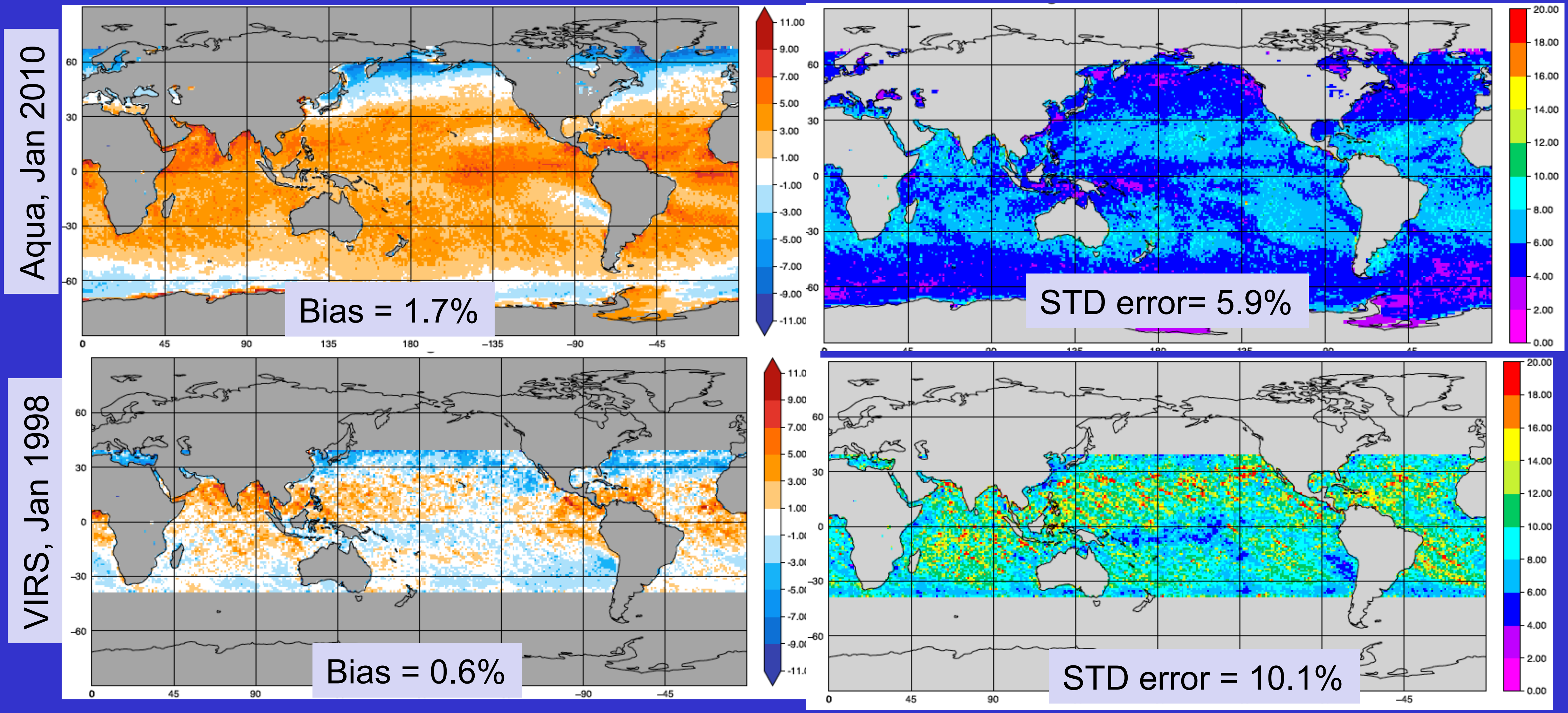
Observed NB and BB angular bin linear regression standard errors (%)





- The TRMM precessionary orbit allows for greater SZA,VZA, and RAA sampling. Limited to VZA<45°
- The Aqua sun-synchronous orbit has a very limited VZA, RAA sampling range. The SZA sampling is dependent on latitude

MODIS/VIRS 0.65µm RTM BB – CERES radiance, all-sky footprints



• The Aqua comparison has limited angular range, whereas the TRMM compares the full range of angles

MODIS/VIRS 0.65μm RTM BB – CERES radiance

All-sky	slope	Bias (%)	Stderr (%)	slope	Bias (%)	Stderr (%)
Terra	0.986	1.5	5.1	0.962	3.5	5.2
Aqua	0.977	1.7	5.9	0.951	4.9	6.7
VIRS	1.012	0.6	10.1			

Clear-sky	slope	Bias (%)	Stderr (%)	slope	Bias (%)	Stderr (%)
Terra	1.015	3.6	3.3	0.971	3.3	3.9
Aqua	1.026	2.9	3.6	0.956	3.7	4.2
VIRS	1.033	3.2	9.3			

Ice clouds	slope	Bias (%)	Stderr (%)	slope	Bias (%)	Stderr (%)
Terra	0.979	1.8	3.5	0.958	3.3	3.6
Aqua	0.967	2.1	4.1	0.955	4.5	5.1
VIRS	1.023	-0.8	6.7			

liq clouds	slope	Bias (%)	Stderr (%)	slope	Bias (%)	Stderr (%)
Terra	0.974	1.0	4.3	0.952	3.6	4.2
Aqua	0.968	1.4	5.0	0.943	5.5	5.2
VIRS	0.999	0.3	8.5			

- The RTM NB and BB reflectances agree more with the MODIS 0.64μm than the 0.86μm channel
- Many GEO visible spectral response functions extend over the 0.86μm domain

- Currently using angular bin centers. Implement angular bin interpolation

- Examine partly cloud cases to ensure proper subfootprint NB to BB conversion

- The GEO NB to BB algorithm will be applied at the pixel level for Ed5. Code is almost ready to compare GEO and CERES reflectances

Conclusions

Conclusion

- FluxByCldType product has been released May 8, 2020 and is orderable on the tool
  - Still working on more FBCT subsetter features, 7x6 plots, and regional cloudtype flux timeline plots
  - Subsetting team trying to get off old hardware and onto virtual machines
- The TISA group is ready to migrate from SYN1deg-Aqua to SYN1deg-N20
  - Need to process August 2020, with half the month with Aqua and the other half with N20, for TISA products and EBAF processing
- The calibration group is ready to use NOAA-20 as the forward processing imager to inter-calibrate GEOs while maintaining the Aqua-MODIS calibration reference
  - Also work with Jack Xiong's group to intercalibrate MODIS and VIIRS IR channels
- The TISA and clouds group has implemented the KD tree algorithm to generate IR imagery when GOES-17 has nighttime degraded imagery
  - The KD tree temporal interpolation was superior to traditional TISA temporal interpolation
- Continue to work on TISA Edition 5 code improvements
  - Almost ready to demonstrate the Temporal interpolation and averaging cloud container written in Fortran object-oriented code.
  - The SW narrowband to broadband algorithm is in final stages of development and code is being prepared to validate the algorithm with GEO and CERES coincident data